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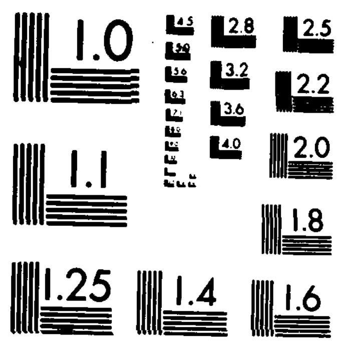

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ESTIMATING MATERIAL HANDLING EQUIPMENT (MHE) AND MANPOWER REQUIREMENTS FOR AN AIR FREIGHT RAMP OPERATION USING SLAM II

THESIS

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AFIT/GLM/LSM/86S-24

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THESIS

Presented to the Faculty of the School of Systems and Logistics

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Master of Science in Logistics Management

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Michael R. Fredette

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Abstract

This thesis identified an Air Force need for an accurate, timely means of determining an air freight terminal's material handling equipment (MHE) and manpower requirements. The need was then justified by a review of pertinent literature. To maintain a workable scope, the research addressed ramp operations only. Then, two SLAM II simulation models were developed, verified, and validated.

The models differed in the way arriving aircraft were created. Model 1 generated aircraft using a separate create node for each aircraft while Model 2 used a single create node for all aircraft. The air freight ramp operation at Wright - Patterson AFB, Ohio provided the necessary data for model development and validation. Mann - Whitney U tests and small sample tests for the difference between two means were used to test the models' ability to predict MHE and manpower requirements for the air freight ramp operation. Both models proved to be successful predictors of MHE and manpower requirements at the 95% confidence level. Also, Model 1, at the 95% confidence level, proved to be a better predictor than Model 2. Lastly, the models were recommended as methodological guides for the development of an air freight terminal resource requirement determination model.

ESTIMATING MATERIAL HANDLING EQUIPMENT (MHE) AND MANPOWER REQUIREMENTS FOR AN AIR FREIGHT RAMP OPERATION USING SLAM II

I. Introduction

This thesis develops and validates two SLAM II simulation models which estimate material handling equipment (MHE) and manpower requirements for an air freight ramp operation. This chapter provides a thesis overview, develops the management problem, and proposes a methodology for solving the management problem. A chapter summary reemphasizes these major topics.

Thesis Overview

The central research question is, "Can a computer based simulation model accurately estimate an air freight ramp operation's MHE and manpower requirements across the range of expected workload conditions?" The first chapter develops this question by illustrating the importance of the economical use of resources, by stating the limitations of the current resource requirement determination techniques, by hypothesizing the objectives of wartime resource requirement determination techniques, and by specifying the USAF problem. The rest of the chapter scopes the problem down to a manageable size and proposes a solution methodology.

The second chapter validates the management problem by tracing past USAF efforts to address it. Furthermore, it justifies the methodology used to develop a solution to the problem. The third chapter describes an air freight ramp operation, the SLAM II models developed to simulate that operation, and the model validation process. It addresses resources, assumptions, work flows, values, value distributions, activities, and events all in the context of SLAM II design. The fourth chapter describes the results of model verification and validation. The last chapter assesses the models' utility and limitations, recommends enhancements, and states the conditions for their future use.

Economical Use of Resources

War is but a shade in the minds of men, given substance through the application of resources. Military resources, however, are best applied when adhering to one of Karl Von Clausewitz' Principles of War, the Economy of Forces. The Economy of Forces states that no more nor no less than the required number of resources should be applied to any military effort (8:158). A principle of transportation, one espousing maximum utilization of equipment and personnel, echoes Von Clausewitz' thoughts (19:17). Obviously, the objectives of any military effort are best supported by employing the appropriate types, amounts, and mix of resources. An aerial port's peacetime and wartime mission

of processing inbound surface and air freight for onward movement by air or surface is no exception to these principles. Therefore, aerial port commanders, senior command authorities, and war planners and executors, during peace and war, seek answers to questions concerning aerial port capacity and capability, and resource requirements, utilization, shortfalls, and surpluses.

Resource Requirement Determination Processes

Material Handling Equipment. During peacetime several means are used to determine resource requirements. One category of resources is MHE which includes specialized aircraft loading vehicles called K-loaders, forklifts, towing vehicles called tugs, tractors and trailers, and nonmoterized, towable pallet carriers called pallet dollies or slave pallets. Air freight MHE allowances are prescribed by Table of Allowances (TA) 010. TA 010 establishes a range of air freight terminal classes based on two workload measures; the tons of cargo handled and the number of aircraft worked per month. The class of each air freight terminal is determined by a command functional manager. This command functional manager semiannually assigns a class to each air freight terminal based on the workload measure which justifies the highest; that is, the largest class. The manager calculates each measure by averaging the previous six month's workload data (14:A1,B1,C1). With each terminal class is an associated set of MHE allowances (14).

More importantly, there is no one accepted method of determining the proper types, amounts, or mix of MHE associated with each class. The use of past experience and trial and error have been the most widely used methods of determining MHE resource requirements for air freight terminal classes (21; 22:5; 42). Transportation conferences have also been used to determine air freight MHE requirements (11; 21). In recent years, a number of algorithms and simulations have been developed and adopted to answer questions concerning MHE utilization and aerial port capacity and capability though none have been officially adopted for resource requirement determination (24; 31). In retrospect, the use of the MHE requirement determination technique has been adequate during peacetime as evidenced by the accomplishment of the air freight mission with MHE resources identified by the current technique (31). However, the use of static, historical data every six months and subjective perceptions of needs to determine an air freight terminal's MHE requirements during war are questionable. In wartime, the applicability of such procedures is suspect because historical peacetime data may be invalid and because the cycle time may not be responsive enough (21).

Manpower. An air freight terminal's manpower requirements are determined by the employment of mathematical equations (15). Some of the equations are

lines of best fit derived through regression analysis (15:1); others are simple algebraic equations derived through observation, experimentation, or trial and error (15:Atch 2). Both types of equations may have one or many variables. These variables are determined by the USAF manpower community at the unit, command, and service level. The values for these variables are often derived from historical workload data or they are the results of other manpower equations which in turn were derived from historical workload data (24).

Manpower requirements are generally quantified through an annual application of the manpower formulas (15:2). Sometimes, the manpower community uses direct observation to determine manpower requirements when a new mission has been established or when there has been a significant change in the mission of an established unit. Though the formulas are public information, the derivation of the formulas and the assumptions upon which they are based are not readily available outside the manpower community. Nonetheless, this resource determination process appears to provide sufficient manpower during peacetime because the air freight mission is being accomplished with the manpower identified by the current technique (24; 31). The wartime utility of this methodology, like the methodology used to determine MHE requirements, is questionable. Once again, historical data may be invalid and cycle response time too long (21).

Facilities. Facility requirements are determined through group consensus involving experienced transporters, civil engineers, and industrial engineers. The application of Air Force facility, storage, mechanized material handling system, construction, and engineering standards guides this resource requirement determination process. This process is applied on an as required basis when mission changes require new or different facilities, when old facilities wear out, or when new technology makes old facilities obsolete. The success of this process depends on the ability of transportation personnel to identify their true facility requirements and their ability to communicate these requirements to the design engineers. Also paramount are the abilities of the engineers to understand these requirements and to design a facility that meets them.

Notwithstanding financial constraints, peacetime acquisitions of new or remodeled facilities are generally more time consuming than the acquisitions of either MHE or manpower. During war the acquisition time generally shortens for all three resources though the acquisition of facilities is still a lengthy process. Lastly and most importantly, MHE, manpower, and facilities operate synergistically where a change in the availability of one resource affects the need of another. The resource requirement determination method for each resource generally neglects the presence or absence of other resources. In

such a case the economical use of current resources must be questioned.

Wartime Requirements

Attention will now focus on the wartime environment of an air freight terminal in order to identify wartime resource requirement determination needs. During war the cargo processing mission of an air freight terminal exhibits two primary changes. First, workload increases rapidly and is sustained for the duration. The first few days of a war will likely be characterized by a large surge of material being transported to the theater of operations (4:7.35). Furthermore, high levels of air transport will be sustained throughout the war because the nature of modern and future warfare is and will be characterized by massive consumption of military materials. When workload increases MHE and manpower requirements also increase.

Second, the workloads and locations of an air freight terminal can change quickly. The AirLand Battle of the future requires initiative, flexibility, and offensive maneuvers (16:III-6; 38; 41:21-22). The battle area will be fluid and aerial ports must be responsive to changes in the movement of forces (5:5; 32:69; 41:24). Additionally, the global extent of our national interests can result in the employment of forces and aerial ports any where in the world (6:1; 9; 16:III-7). One such example was the 1983 invasion of Grenada where the U.S. established an aerial port in

hostile territory within the first 24 hours of the operation (9). When an aerial port unit relocates, its facilities and workload changes, and, consequently, its resource requirements change.

The war mission of an air freight terminal, therefore, results in increased resource requirements with the possibility of rapid fluctuations in those requirements. This applies to all air freight terminals whether they are owned by MAC, AFLC, or other commands, or located in the CONUS or in the theater of operation. Furthermore, theater air freight terminals must be responsive to the needs of supported units whose locations are subject to change. Therefore, changes in resource requirements as result of changes in workload or location must be quickly identified so that an air freight terminal can take necessary actions to obtain needed resources.

USAF's Problem

The problem is clear. Air freight terminal managers during wartime must be able to identify and estimate resource requirements quickly when workload or location change. Current MHE and manpower requirement determination methods cannot meet these wartime needs because they utilize historical workload data. Such data may not reflect wartime workloads because of the possible differences in the volume of and types of cargo handled. Furthermore, these current resource requirement determination methods were designed to

be employed once or twice a year. Consequently, they may not be timely in a contingency environment as fluctuations in the volume and types of cargo to be processed may change daily. Lastly, current methods of MHE and manpower requirement determination neglect the synergism that exists between MHE, manpower, and facilities in carrying out the mission of an air freight terminal. Recognition of this synergism is imperative to identifying the appropriate types, amounts, and mix of resources required to perform the mission.

Consequently, of all the questions that could be asked of an air freight terminal's resources; that is capacity, capability, utilization, shortfalls, surpluses, and requirements, one of the more important is, "What resources are required by an air freight terminal in order to carry out its war mission." Why, in times of modern warfare, is this question one of the most important? The enemy fights the same war as we do. It too will be on the offensive; it too will be taking the initiative (3:43). If the US does not adhere to the Economy of Forces principle, if it does not respond to the needs of the battlefield by providing inadequate support it will risk defeat.

The literature review in the next chapter illustrates that each of these questions has been addressed to some degree, the least of which has been the question of resource requirements. Without the means to quickly and accurately

determine and fulfill resource requirements the USAF must tailor cargo flow to the in place or planned air terminals and their attendant resources. This is a resource superior - mission subordinate view of cargo flow. What is required, however, is the means to quickly and accurately determine resource requirements so that air terminal resources can be tailored to meet the expected cargo flow. This is a mission superior - resource subordinate view of cargo flow.

Scope

The need is indeed sizable. In order to reduce the research problem to a manageable size matters of scope are addressed. First, the number of interrelated activities, events, and resources involved in accomplishing an air freight terminal's mission are extensive. Consequently, only one segment of an air freight terminal will be examined in this thesis. Of the three separate work areas within a terminal, the warehouse area, the staging area, and the ramp area, only the latter will be included in the scope of this research effort.

In addition, the reference to wartime utility poses problems with validation. Wars cannot be created to test a model. Instead, peacetime data obtained from Wright-Patterson's LOGAIR terminal was used to develop and validate both SLAM II models. While aircraft types, cargo characteristics, and workload volume differ between a contingency aerial port and Wright-Patterson's LOGAIR

terminal; cargo, resources, facilities, and cargo processing activities are similar enough to make a comparison. Such a comparison is not without its limitations and these will be addressed in Chapters III and V.

Another question of scope concerns the determinants of MHE and manpower requirements. Already mentioned is the idea that facility acquisition, even in war, is a lengthy process. Furthermore, an air terminal might be required to relocate in which case it will be constrained by the facilities at the new location. For these reasons, facilities will be considered unalterable in the short term, and, therefore, a determinant of MHE and manpower requirements. Workload, of course, consumes MHE and manpower resources and it is also a determinant of resource requirements. Aircraft type also influence MHE and manpower requirements. The same amount and type of cargo would require different MHE and manpower resources if it was all delivered by C-141Bs or C-5s or B-747s, etc. Therefore, an air freight terminal's MHE and manpower requirements will be viewed as a function of the port's fixed facilities, the expected workload, and the load characteristics of the aircraft to be serviced.

These three factors were used to estimate MHE and manpower requirements. Fixed facilities were represented in both models as resources in limited amounts. Their use in the performance of air freight activities influences what

work can be done and, therefore, influences MHE and manpower requirements. Expected workload was represented in both models as cargo on arriving aircraft which required a sequence of activities and several resources in order to be processed. Aircraft arrivals can be modeled by either creating a single aircraft arrival for each scheduled aircraft arrival or by creating all aircraft arrivals based on a daily flow of aircraft into an aerial port. Consequently, two models were developed; one created aircraft arrivals on a one for one basis according to a schedule and the other created aircraft arrivals according to an average daily arrival distribution. The MHE and manpower estimates of each model were compared with each other and with empirical data. Lastly, aircraft type was represented as an attribute of the arriving workload. This attribute determined the specific sequence of activities and resources required to process the cargo.

Solution Methodology

Having identified the research problem a method for solving it must be developed. The first step in developing a solution is identifying the methodology's objectives. The solution methodology should validate the problem, select a solution design, construct the solution, select a solution test, test and analyze the solution, and report research results (17:Chap 3). In order to validate the air freight resource requirement determination problem a review of

professional literature on past Air Force efforts addressing it was required. Such citation of authority established the significance of the problem and the importance of finding a solution to it.

Next, a solution design, the type of tool that can solve this problem, is selected. An analysis of the resource requirement determination needs was used to select the appropriate solution tool. Because past experience and trial and error can not meet wartime needs the solution tool has to provide resource requirement estimates before they are needed. In addition, the impracticality of experimenting on actual air freight terminals, either in peace or war, pointed to the use of a model as the solution tool. An air freight ramp operation, then, had to be modeled so that estimates of the required resources could be available when needed.

For this problem the models had to exhibit three attributes. First of all, they had to allow the decision maker to retain control of the decision, especially during war. The models had to support the decision maker by providing estimates of the resources required and by allowing the decision maker to accept the estimates or manipulate them as desired. Second, the models had to provide resource requirement estimates quickly, especially in times of war. A response time of less than a day, a few hours, or even a few minutes would not be an unrealistic

model attribute for wartime use. Last, the models had to accurately assess the resources required to perform the mission. They had to be powerful enough to handle the multitude of activities, events, and resources that exist in an air freight ramp operation and sophisticated enough to replicate their synergistic and dynamic effects.

The models, then, had to support the decision maker by providing quick, accurate estimates of required resources. A continuation of the literature review examined the most applicable modeling techniques and their attributes and selected the most appropriate one, in this case simulation. The literature review continued to explore the solution tool in greater detail and selected the simulation language, specifically SLAM II, to be used.

At this point the models were created. Creating the models was the crux of this thesis effort because the problem would have remained unsolved if a model could not have been created. Creation of the models by a three stage process is documented in the third chapter. The three stages are model building, data acquisition, and model translation (29:10; 35:13). Model building involves abstracting an air freight ramp operation into a set of mathematical-logical relationships (29:10). Direct observation of an air freight ramp operation, specifically the 2750 Air Base Wing's (2750 ABW/DMTA) air freight ramp operation at Wright-Patterson AFB, Ohio provided the input

for the first stage. Data acquisition, the second stage, relied on direct observation of the 2750 ABW's air freight ramp operation in addition to tapping their historical records. Acquired data was used to establish values and value distributions for air freight ramp operation events and activities. Model translation, the third stage, involved preparing the model for computer processing. This stage developed two SLAM II programs to run on the DEC VAX 1170 computer at the AFIT School of Systems and Logistics. Chapter III details all three stages of the model building process.

After creating the models the means to test them was selected. Appropriate statistical tests were examined and selected in the methodology chapter. The models were then verified and validated. Verification, testing the logic of the models, was accomplished through two means. Data which exercised all elements of the simulation program were used as input to the simulations and the results were analyzed for their plausibility. Furthermore, the models and their assumptions were presented to the Wright-Patterson AFB assistant air terminal manager (ATM) and several shift managers for their opinions on the model's logic and its assumptions. Their responses were reported in Chapter IV.

Validation of the model, the establishment of a correspondence between the the model's output and empirical data, was accomplished by comparing simulated and actual

amounts of MHE and manpower used to accomplish the daily mission of the 2750 ABW's air freight ramp operation. A value of the goodness of fit between the two resource distributions was used to determine the validity of the model. Lastly, the results of this research effort were reported. The fifth chapter assesses the models' utility and limitations, recommends, enhancements, and states the conditions for their future use.

Summary

This chapter accomplished three things. First, it presented an overview of the thesis. Second, it developed the research problem by comparing resource requirement determination needs with current capabilities. Third, it proposed a methodology for developing a solution to this thesis' basic research question, "Can a simulation provide quick, accurate estimates of an air freight ramp operation's MHE and manpower requirements?"

II. Literature Review

This chapter reviews literature on two subjects. First, it examines past USAF efforts to address the subject of measuring air freight resources. Citation of authority, in this case, is used to establish the significance of the problem and the importance of developing a solution. Second, this chapter reviews the more applicable modeling techniques in order to select the most appropriate technique. A continuation of this part of the literature review selects the most appropriate simulation language. This examination, in conjunction with the methodological precedents of prior research efforts, will justify the chosen methodology. A summary of the literature review concludes the chapter.

Significance of the Problem

The need to quickly and accurately determine an air freight ramp operation's MHE and manpower requirements, especially during war, is indeed significant. Chapter I illustrated the wartime impotence of current resource determination techniques. Several USAF research efforts were reviewed in order to validate the significance of this research problem and the need to develop a solution. These efforts are grouped as early efforts, Air Force Logistics Management Center (AFLMC) efforts, and recent individual efforts. These efforts addressed MHE, manpower, and

facility requirements, though, they have favored research on MHE requirements. Note that the research question and the scope of this thesis are not duplicated by any previous effort.

Early Efforts. In 1968 the National Military Command System Support Center (NMCSSC), in response to the needs of the National Military Command Authorities (NMCA), developed the Simulator for Transportation Analysis and Planning (SITAP) (13:1-1). The NMCA needed the ability to model the flow of cargo supporting a theater war in order to identify port, ship, aircraft, and truck utilization rates, bottlenecks, and transportation system response time (13:1-2). A model was used because of the impracticality of obtaining such information from the real world. SITAP was the solution. SITAP simulated the flow of cargo from mode to mode (vehicle to vehicle) in support of a theater war. It utilized FORTRAN IV as a programming language and it ran on an IBM 360/50 main frame computer via card input. Both the computer and the method of input were representative of the period's technology.

Consequently, SITAP satisfied the NMCA's needs at the time, although it had no query capabilities (13:1-3). Furthermore, the program was unresponsive. "The action officer, who require(d) rapid access to data dealing with an operational problem, (did) not obtain any help from SITAP" (13:1-3). However, SITAP did identify port facilities as

one determinant of how many aircraft can be worked at a time (13:2-10). As stated in the first chapter, manpower and MHE requirements are a function of fixed facilities in addition to expected workload and aircraft characteristics. SITAP also indicated that service time is a function of the synergistic use of equipment and manpower at the ports (13:2-11). Based on that indication this thesis assumes that MHE and manpower act synergistically and that the requirements for either one are partially determined by the presence or absence of the other in addition to the three determinants previously mentioned.

SITAP was one of a series of models developed by the DOD from 1964 to 1979 to address strategic mobility (20:63-82). These models included a series of linear programs which culminated with the development of POSTURE (20:63-71). These linear programming models were developed to provide an optimal solution, in effect, a plan for the intertheater deployment of general purpose forces. POSTURE utilized FORTRAN as its programming language, was resident on IBM 7044 and 360/65 computers, and was capable of creating linear programs from data input. Consequently, it enjoyed a measure of flexibility not previously known. However, POSTURE became obsolete at the advent of computer simulation (20:67-71).

Four simulation models culminating with the Interactive Strategic Deployment Model (ISDM) provided detailed

information on how an intertheater deployment of general purpose forces could be carried out (20:72). All these models maintained a broad perspective of strategic mobility by modeling the flow of personnel and cargo through numerous ports. These models, with the exception of ISDM, could not model a single port (20:74). Manpower and MHE requirement determination were not the focus of these models, instead, the models concentrated on facility requirements in the gross sense and on deployment routing and scheduling. Port resources were not fully addressed through simulation until single port models started to appear.

In 1970 Headquarters Tactical Air Command (HQ TAC) foresaw the need for a rapid, economical means of studying the operations of a single air freight terminal (39:12-1). Specifically, the need focused on the ability to support engaging forces via contingency air terminals. Once again, a model, specifically a simulation, was developed to satisfy that need because of the impracticality of obtaining data from real world contingencies. Simulation of a Contingency Air Terminal (SIMCAT) was developed on an IBM 360 series computer using the General Purpose Simulation System (GPSS) programming language. The simulation's inputs were contained on punched cards and considerable attention was required to prepare the input data (39:12-1). More importantly, this model emphasized the speed of processing in addition to the economic practicality of modeling. This

thesis effort also emphasizes speed of processing in order to quickly determine resource requirements.

In the late 1970's the questions concerning the resources of an air freight terminal became more encompassing and refined. Headquarters Military Airlift Command's (HQ MAC) Directorate of Transportation and the United States Air Force Europe's (USAFE) Directorates of Logistics and Transportation were interested in determining MHE, manpower, and facility utilization rates, and air freight terminal capability and optimum throughput capacity (40:2). The specific question to be answered was how much cargo can be sent through an aerial port with given resources. This exhibited a purely resource superior - mission subordinate view of cargo flow. Knowing this information would allow war planners and executors to sequence cargo through established aerial ports in order to maximize the resupply of engaged forces. Though the fluidity of resupply and cargo flow requirements were recognized at this time, the notion of tailoring aerial port locations and resources to meet cargo flow requirements was not yet prevalent.

During this period there were at least three different efforts to model an aerial port cargo operation (29:534-535, 547; 30; 31; 40). All three simulations were developed using the Q-Gert programming language; the first by V. J. Auterio in 1974, the second by S. Duket and D. Wortmann of

Pritsker and Associates, Incorporated in 1976 (28:275; 29:534-535,547), and the third by the USAFE Directorates of Logistics and Transportation in 1980 (40). These efforts sequentially developed and refined a Q-GERT simulation of the Dover AFB aerial port cargo operation.

The work done by Pritsker and Associates on contract to HQ MAC produced a model of the Dover AFB air freight terminal. The model was developed to answer three specific questions; should new MHE be introduced into a port, how many aircraft can be worked at a given time, and what is the maximum throughput of a terminal (28:275). The model could be used to determine resource requirements by obtaining the required information from several simulation runs (28:284). However, the model was not used to determine resource requirements nor was it used for any other purpose (23). The Operations Research Division at MAC moved away from functional area analysis to a broader systemic analysis; that is, they developed another model to simulate the operation of an entire aerial port and abandoned the model that simulated the air freight terminal. Follow on models did not allow for air freight terminal resource requirement determination because they lacked the detail of Duket's model (23). Nonetheless, Pritsker and Associates demonstrated the applicability of simulation theory to the study of air freight terminal operations.

The third model, the Air Cargo Reception and

Distribution Model (ACRDM), represented the culmination of sophistication in this series of efforts (24). Given facilities, manpower, and MHE, this model simulated the operations of the Dover AFB air freight terminal. Over 90 variables and parameters were used to calculate the terminal's throughput capacity and report on cargo processing performance and resource utilization (40:2). This simulation operated on a Honeywell System 6000 minicomputer in the batch mode although a request for simulation and input data could be entered via card, CRT, or teletype (40:5). A response time of 24 hours was typical though a 30 minute response time for one simulation run was possible if the computer was dedicated to the simulation (40:6). User queries on resource requirements could be answered via multiple runs. For example, it was possible to determine the MHE and manpower requirements by progressively simulating the operation with different resource bases. At one run per day this could be a time consuming factor. Such response times limited these four models to peacetime war planning, and made them impractical for emergency war planning or war execution. In the same light, these models have not been used to justify facilities, manpower, or MHE, during peace or war.

AFLMC Efforts. In 1978, Colonel Quirk, as the Air Force Logistics Managements Center's Director of Transportation, produced the Air Terminal Throughput

Capability Study in response to HQ USAF Directorate of Transportation tasking (31). This study was an investigative exercise for the larger and currently ongoing Joint Chief of Staff (JCS) Aerial Port of Debarkation (APOD) Study which focused on strategic mobility (31). Colonel Quirk developed a manual algorithm which would determine an air terminal's throughput capability by weighting several factors such as MHE, manpower, workload, and facilities (31). The focus of his study was throughput capability, defined as the realistic throughput that could be achieved with given resources, and not throughput capacity, defined as the theoretical throughput that could be achieved at an air terminal (31). Though air terminal resources were addressed in terms of work performed resource requirement determination was not.

All efforts previously described concentrated on providing war planners and executors the tools to tailor cargo flow to terminal capability. Each model's success was limited by technology and their utility was limited by the resource superior - mission subordinate view of cargo flow. Such a perspective severely restricted the ability of these models to answer questions concerning resource requirements. In fact, these models had little influence the MHE and manpower requirement determination processes. Furthermore, contingency MHE and manpower requirements were not adequately addressed.

In 1982 the USAF decided that a more accurate resource requirement determination process for MHE was absolutely essential to war planning and readiness (11). Furthermore, the Air Force committed itself to developing new resource determination techniques based on mission factors. This was the first indication of tailoring the aerial ports and their resources to cargo flow requirements. Shortly thereafter, HQ USAF tasked the Air Force Logistics Management Center to develop an MHE requirement determination methodology for large MHE; that is, 40K/25K K-loaders and 10K forklifts. Consequently, AFLMC's Mr. Sampson developed two equations to determine 40K/25K K-loader requirements and 10K forklift requirements, respectively. These equations were base on logical resource - work relationships expressed by seven variables in the first equation and five in the second (34:3). Although this methodology represented a significant departure from the trial and error methodology it did not address resource - to - resource relationships; that is, how MHE requirements are influenced by available manpower and facilities. This methodology did not enjoy the confidence of senior transporters either because of its novelty or its lack of validation and the consequences of implementation or both (21). Consequently, this methodology was not adopted as the Air Force's requirement determination process for large MHE. This first AFLMC study did not address 4K/6K forklift requirements because the conditions of their use in

the warehouse were too complex for a simple equation to model. A simulation was recommended as an appropriate tool for determining 4K/6K forklift requirements.

Still interested in developing new resource determination techniques, the Air Force Directorate of Transportation tasked AFLMC to develop a 4K/6K model (22:1). HQ MAC also exhibited interest by cosponsoring the project (22:1). AFLMC's Major King and First Lieutenant Yost developed a comprehensive FORTRAN IV simulation of an air freight terminal warehouse for use on the Z-100 microcomputer (22; 42). The simulation required the input of available facilities and MHE while assuming adequate manpower (22:3-4). Using over 30 variables and parameters representing resource inputs, resource - to - resource relationships, and resource - to - work relationships, the model simulated an air freight warehouse operation and reported back on cargo processing performance and 4K/6K forklift utilization (22:3).

This was not a great departure from the ACRDM. In fact, both models are based on the resource superior - mission subordinate perspective. Neither model directly answers how many resources of what type are required by an air freight terminal even though the AFLMC simulation was intended to answer such a question. However, technology has compensated greatly for the limitations of the 4K/6K forklift model. This simulation is easy to use and

understand and it also operates real time on a transportable microcomputer. Consequently, the microcomputer is very responsive. Results of a simulation run can be retrieved in 15 to 30 minutes. This responsiveness and the model's user friendly design allows the user to manipulate inputs and perform "what if" analysis. By manipulating the MHE inputs while using a constant workload the user can determine how many 4K/6K forklifts are required to do the job in addition to how well they do the job.

Recent Individual Efforts. Since 1982 several students from the Air Force Institute of Technology have addressed aerial port resources in four separate theses. Captains Reusche and Wasem in their 1982 thesis addressed the question of manpower requirements for a tactical aerial port (33:1). They developed a Q-GERT simulation model to generate data used in the construction of several tactical aerial port manpower formulas (33:12). They validated the simulation and the manpower formulas through comparison with current wartime manpower allocations (33:Chap 7). However, the validity of those allocations were suspect and the topic of Captain Starkey's thesis.

Captain Starkey in 1985 tested the contingency manpower allocations for an aerial port through selective and sequential manual "modifications" to current standards (37:ix,36-42). Though hypothesized manpower needs were found to differ from the standard allocations, justification

and validation of the "modifications" were incomplete.

Major Christensen and Captain White in their 1983 thesis examined an aerial port of embarkation mission. They developed a simulation model of an aerial port personnel and cargo reception and processing operations. This model was intended to determine the optimum mix of required resources so that operation plans could be more accurate and realistic in the future (6:Chap 1). The model and the validation process illustrated the potential of simulation to determine resource requirements. Lastly, Captain Cuda in his 1985 thesis examined the problems associated with limited aircraft parking space at an aerial port (10:1-4). He used a SLAM II simulation to determine delays and diversions associated with inadequate aircraft parking space.

Summation. Over the last twenty years various simulation and mathematical models have been developed to answer a number of questions concerning aerial port cargo operations. These models attempted to provide users with quick, economical, practical, and accurate information. How successful they were depended on available technology and model design. More importantly, technology and simulation sophistication have progressed to the point where the conditions of quick, economical, practical, and accurate information generation can be met. This, of course, requires a properly designed model.

The seeking of resource specific information has, in

varying degrees, driven the development of all these models, though, none of them have been exclusively designed to provide resource requirement information. Often this was the result of a resource superior - mission subordinate perspective of an aerial port's role in a contingency environment. Nonetheless, the significance of this thesis' research problem and the importance of finding a solution to it are fully supported and justified by the weight of past USAF efforts to address it. What has not been tried but will be by this thesis is an attempt to use a mission superior - resource subordinate perspective of an aerial port's role in a contingency environment to determine resource requirements.

More specifically, the models reviewed here provided information on deployment flow and scheduling, strategic mobility, air terminal throughput capability and capacity, resource utilization, and cargo processing performance. Only the simulation model developed by Pritsker and Associates, the ACRDM, and the 4K/6K Forklift model have the capability to determine resource requirements. This capability can be realized through multiple simulation runs. Because these models generally have fixed amounts of resources the processing of progressively greater amounts cargo must be simulated in order to determine the point excess resources are not utilized; that is, not required. This thesis will develop two separate models, each

exhibiting a different aircraft creation processes, that will determine manpower and MHE requirements on one simulation run by allowing MHE and manpower resources to be unlimited in the model.

Modeling Technique Selection

The first step in solving a problem is to formulate it and define it as a research question (1:23). This thesis' research question is, "Can an air freight ramp operation's MHE and manpower requirements be quickly and accurately estimated using a SLAM II simulation model"? This section of the literature review justifies the selection of a SLAM II simulation model as the tool to answer the research question and solve the problem of interest.

Modeling Justification. Chapter I has shown that this thesis is as much an effort to determine resource requirements as it is an effort to develop and test the means to do so. The solution, however, is subject to constraints. First, the determination of resource requirements via manipulation of and experimentation with a functioning ramp operation is costly, time consuming, and impractical during peace and possibly disastrous during war. Even if adequate funding were available the methodology would be unresponsive. If an actual ramp operation cannot be the subject of manipulation then a model of an air freight ramp operation must.

A model is a representation of reality (1:60; 35:4-5)

used as a tool for prediction and as an aid to experimentation. Models can be either descriptive or explanatory. An explanatory model contains controlled variables and a descriptive model does not (1:61). In discussing the problem of interest a descriptive model was alluded to. It was stated that the MHE and manpower requirements of an air freight ramp operation were dependent not only on each other but on fixed facilities, workload, and aircraft characteristics. Therefore, an air freight ramp operation's MHE requirements can be expressed as a function of available manpower, fixed facilities, expected workload, and aircraft characteristics:

$$\text{MHE} = f(\text{Manpower, Facilities, Workload, Aircraft}) \tag{1}$$

Similarly, an air freight ramp operation's manpower requirements can be expressed as a function of available MHE, fixed facilities, expected workload, and aircraft characteristics:

$$\text{Manpower} = f(\text{MHE, Facilities, Workload, Aircraft}) \tag{2}$$

The relationship between MHE and manpower requirements is such that they need to be determined simultaneously to enjoy any level of accuracy. The actual models that are produced by this thesis effort are explanatory models. They offer the "whys" and "hows" of an air freight ramp operation in addition to the "what" of the descriptive model. This

explanation is covered in the methodology chapter.

<u>Modeling Techniques</u>. There are several mathematical modeling techniques that can be used to study an air freight ramp operation. Linear programming, network modeling, waiting line models, and computer simulation, in particular, are applicable. Linear programming is a mathematical tool that identifies an optimal solution to a problem (2:Chap 2). The problem is generally expressed as an objective function which is to be maximized or minimized. If enough was known about the relationships between all the elements, including manpower and MHE, and how they influence an air freight ramp operation then resource requirements could possibly be determined using linear programming. Such a linear program would most likely minimize MHE and manpower while a minimum of work to be performed or facilities to be used would act as constraints on the objective function. Previous studies have generally focused on one resource to the exclusion of others. Consequently, the relationships between the elements of an air freight ramp operation have not been sufficiently established to formulate a linear program model. Nonetheless, if sufficient information were available to develop an objective function and constraints, the limitations of linear programming; such as, the inability to assure integer solutions and the massive computational requirements, would reduce it to a feasible but impractical methodology (20:66-67).

Network models are applicable to a wide variety of problems. Phenomena that be represented by modes or events and branches or activities can be expressed as networks. Nodes or events represent places or points in time and are analogous to a freight dock, an aircraft, or the start of an aircraft loading operation. Branches or activities represent actions that must be taken to arrive at different modes through time or place. They are analogous to the actual unloading of an aircraft or the travelling between and aircraft and a dock (2: Chaps 9, 10; 28:9). Networks can be used to model an air freight ramp operation. If the model is sophisticated enough; that is, if it has a sufficient number of routes representing all possible combinatorial uses of MHE and manpower, it could be used to determine resource requirements by identifying a shortest route (resources) while maintaining a desired flow (workload). A network of this type would be extremely complex to formulate, comprehend, and solve. Formulation and solution of such a model would surely be "breaking new ground."

Waiting line models, called queueing models, are based on a finite number of servers performing activities on some entities. Because the entities' arrival times and the servers' performance times contain a degree of uncertainty, waiting lines, or queues, form (25:95-96). Many of the activities of air freight ramp operation can be described in

such a manner. Aircraft await loading or unloading because MHE or manpower is unavailable or a K-loader awaits unloading because the docks are filled. The use of waiting line models requires significant quantitative aptitude or computer processing. Nonetheless, it is entirely possible to accurately model an air freight ramp operation using queueing theory and its techniques.

Simulation modeling involves developing a mathematical logical representation of a system, in this case an air freight ramp operation, translating that representation into computer code, and running the resulting program in order to obtain useful information about the system (29:4). Simulation modeling is not an optimizing technique. It, instead, mimics "the dynamic behavior of a system by moving it from state to state in accordance with well defined operating rules" (29:6). Once developed, a simulation can be used to conduct experiments without actually creating, disturbing, or destroying the objects of study (29:5). The results of a simulation can offer more than a solution. Data on the objects of study as they flow through the system can offer the decision maker an important perspective of the elements and the behavior of the system. This can foster greater understanding, intuitive thinking, increased experimentation, and enhanced problem solving. Such attributes are essential to a good decision support system design (12:188-191).

In developing a mathematical - logical representation of a system the modeler must adopt a "world view." A world view is a framework for describing the way a system works or changes (29:60). A modeler can view system changes as either occurring discretely, at distinct points in time, or continuously. This discrete world view can be further divided into three orientations; event, activity scanning, and process. An event orientation requires the modeler to define the system changes which occur at specific times (29:66). An activity scanning orientation requires the modeler to define the activities in the system and the conditions for the start and end of each activity (29:67). Finally, the process orientation requires the modeler to describe and define the sequence of events and activities through which the objects of study flow. In short, the modeler describes the process of the system.

The process orientation is a combination of the event and activity scanning orientations. System processes are described by networks with system events as the network's nodes and system activities as the branches. Furthermore, queueing theory is used to describe the flow of entities through the network. The process orientation is simplistic and easy to understand because the process descriptors, verbs which describe the process, are contained within the standardized statements of many simulation languages.

When adhering to the continuous world view a modeler

sees the state of the system changing constantly. Continuous simulation requires the modeler to define, equations for a set of variables whose behavior simulates the real system. Defining these equations often requires mastery of calculus and differential equations. Take note, however, that these world views and their associated orientations are just methods of describing the way a system changes so that a modeler can develop a computer program. These world views apply only to the model and are not associated with the way a system actually changes (27:18). It is, therefore, possible to model the same system with either world view or with a combination of different world views and orientations (27:18).

Modeling Technique Selection. From this review of modeling techniques it is apparent that simulation is the most appropriate. Simulation incorporates both network and queueing theories. Furthermore, it allows the modeler to chose whichever world view or orientation would make the model more accurate or easier to construct or both. Simulation also provides the decision maker with more information of a type which supports sound decision making. Lastly, a simulation is dynamic; an attribute it shares with an air freight ramp operation. Such dynamism allows the concurrent determination of MHE and manpower requirements. This analysis and the precedent of past studies leads to the selection of simulation as the modeling technique.

Simulation Language Selection. There are many simulation languages on the market. GPSS, SIMULA, Q-GERT and SIMSCRIPT are widely used process oriented, discrete simulation languages (18:Chap 7; 29:Chap 12). The most popular continuous simulation languages include the CSLL group and Dynamo (18:Chap 18; 29:Chap 12). SLAM II, however, offers a choice of alternate world views and the opportunity to combine different world views into a single model. In addition, it is easy to learn and use, it is self documenting to some degree, and it offers good error diagnostic capabilities. SLAM II is also available for IBM compatible microcomputers. Though not used for this thesis, conversion of this thesis' programs to microcomputers would not be difficult. The USAF is committed to IBM compatible microcomputers and their transportability would increase the utility of computer based resource requirement determination techniques in peace and war. SLAM II, for several reasons, is the best choice. Consequently, it was chosen as the implementing language for this model.

World View Selection. SLAM's process orientation employs a network structure with branches representing activities and nodes representing queues, decision points, and other events. The operation of an air freight ramp, as previously shown, can be illustrated by a network of activities and has naturally occurring queues. A process orientation would aid the conversion of an air freight ramp

operation into SLAM II code. As a result, this model will use the process orientation.

Summary

This chapter reviewed professional literature on two subjects. It examined past USAF efforts to address the subject of air freight resources, and, consequently, established the significance of the problem and the importance of developing a solution. It then reviewed the more applicable modeling techniques and selected simulation as the most appropriate. A continuation of this part of the literature review selected SLAM II as the language of implementation and the discrete process orientation as the world view. The next chapter will detail the processes used to create the models and validate them.

III. Methodology

This chapter describes and explains the methodology used to develop and validate two SLAM II simulation models. The first section, a description of the WPAFB air freight terminal and its ramp operation, provides the appropriate background information. The next three sections describe and explain the models' assumptions, the empirical data used in the models, and the models' design. The last section explains the models' verification and validation procedures.

The Air Freight Terminal

Mission. The 2750th ABW air freight terminal located at Wright-Patterson Air Force Base, Ohio functions primarily as a LOGAIR terminal. LOGAIR is the United States Air Force's air freight distribution system for the 48 conterminous states (CONUS). In this function the air freight terminal processes cargo for six arriving and departing aircraft each day. This cargo processing includes unloading and loading aircraft and truck-borne cargo, containerizing (palletizing) and decontainerizing cargo, sorting and routing cargo by destination, and accomplishing the associated paperwork.

Facilities and Resources. The terminal consists of a recently constructed building containing office and warehouse areas. Within the warehouse is a state of the art mechanized material handling system (MMHS) consisting of a

cargo routing conveyor system, six pallet buildup pits, and a powered pallet conveyor connecting the pits to two powered docks attached to the terminal. The two powered docks have omni-directional rollers and are primarily used for pallet staging although they also function as a cargo transfer point between the ramp and the warehouse. One dock is capable of holding 15 463L pallets, the USAF's standard pallet, and the other is capable of holding 25 pallets.

Beyond the docks is an aircraft parking ramp with space to park five LOGAIR aircraft. Connected to the parking ramp is a taxiway which leads to the runways and the hot spot. The hot spot is an area designated for the unloading and loading of certain hazardous cargo, mostly explosives. There is enough space at the hot spot to park four aircraft; however, there is no room for MHE or other aircraft to pass around any aircraft at the hot spot. Therefore, only one aircraft at a time can use the hot spot. Lastly, the terminal has six 40K K-loaders, twelve 10K forklifts, one pickup truck, three small trailers, and one tug, and at least two supervisors and eight workers per shift to conduct ramp operations.

<u>Workload</u>. The freight arrives and departs on six LOGAIR aircraft. The six consist of two L-100 and three L-188 aircraft arriving and departing once each day and one L-188 aircraft arriving and departing once each day from Tuesday through Saturday, inclusive. The L-100s hold

sixteen 463L half-pallets which are unloaded and loaded through a rear opening. L-188s hold seventeen 463L half-pallets on the main cargo deck and loose cargo in two belly compartments. All L-188 cargo is unloaded and loaded through side openings. Full sized 463L pallets are sometimes used in both types of aircraft in lieu of half-pallets at a rate of one for two. Each aircraft type requires two 40K K-loaders, two 40K K-loader drivers, one aircraft supervisor, three workers on the aircraft, one dock supervisor, and three workers on the docks for unloading and loading. The L-188s, in addition, require a tug and a small trailer to handle the belly cargo. Furthermore, a pickup truck and a 10K forklift are required for any hot spot operation. Two 40K K-loaders, which hold five full sized or ten half sized 463L pallets, are required even if less than one 40K K-loader load is unloaded or loaded. This is a result of the requirements to resequence LOGAIR cargo and to simultaneously unload and load through both L-188 side doors to maintain aircraft balance. The MHE, hot spot, parking ramp, docks, and supervisory and working personnel necessary to accomplish ramp activities in addition to the ramp activities themselves define the ramp area under study.

Limitations. Although this terminal is not currently functioning in a war environment it is, for this researcher, the only terminal available for observation. The differences between this peacetime LOGAIR terminal and a MAC

terminal in a contingency environment limit the direct application of these two models. Because aircraft types, cargo volume, cargo characteristics, and facilities differ between peacetime LOGAIR and wartime MAC operations this research cannot determine the actual numbers of MHE and manpower required to perform an air freight ramp operation in a contingency environment. This is true because aircraft types, cargo volume, cargo characteristics, and facilities determine model design. If such information were available similar models could be built for contingency terminals. In fact, the assumption that the required information can be obtained and that such models, patterned after these, could be constructed is made or this effort is for naught.

Nonetheless, similarity in MHE, manpower, and unloading and loading activities exists between peacetime and wartime ramp operations. This similarity is assumed strong enough to conclude that if these models can adequately predict MHE and manpower requirements for a LOGAIR terminal given a specific workload and facilities similarly designed models can do the same for a contingency air freight terminal. If enough data is gathered a generic model may be designed. As stated previously, this effort does not attempt to produce a listing of MHE and manpower requirements vis-a-vis expected workloads and given facilities, it, instead, attempts to develop and validate a methodology for determining such requirements.

Model Assumptions

Several assumptions were made for the purpose of developing these two models. First and foremost is the assumption that a model which sufficiently predicts MHE and manpower requirements for a LOGAIR ramp operation can be modified to do so for a contingency air freight ramp operation. This assumption was discussed in the previous section and it, in turn, relies on another assumption. Specifically, it is assumed that the use of MHE and manpower resources throughout a period of time can be described as a distribution with time as the independent variable and resource use as the dependent variable. A third assumption is that a simulation employing network and queueing theory is the appropriate management science tool for developing these models. The literature review provided sufficient support to make this assumption.

Next is a series of assumptions about resource availability and use that are explicit in both models. First, there are only five spaces to park aircraft on the ramp and only one space to park aircraft at the hot spot. Second, only one dock can be used at a time and only one 40K K-loader can be worked at the dock when it is in use. This was the case because the docks were primarily used as staging areas. Third, only one aircraft can be loaded or unloaded at a time and the aircraft worked will be the aircraft with the shortest remaining ground time. These

assumptions were based on observations of WPAFB's air freight terminal ramp operations from 2 July through 19 July 1986. Consequently, ramp and hot spot parking and dock space, in addition to the number of aircraft that can be worked at a time, are modeled in limited quantities and are the workflow constraining variables. Though unrealistic, it is assumed that these resources can not be preempted for higher priority uses. This was done to maintain model simplicity.

Fifth, it is assumed that two 40K K-loaders with drivers, one aircraft supervisor, and three workers will unload and load the aircraft from beginning to end with these exceptions. K-loaders and drivers will transport cargo to and from the dock and remain at the dock while cargo is unloaded or loaded. The first K-loader and driver to complete unloading at the aircraft will be released at that time. All K-loaders and personnel will be released when the aircraft is completely unloaded and the aircraft is terminating. Sixth, one dock supervisor and three workers will unload and load the 40K K-loaders at the dock. These personnel will not be the same personnel that are on the aircraft. Once a K-loader has cleared the dock and no other K-loader is waiting to be unloaded or loaded then the dock personnel will be released.

Seventh, L-188 aircraft require a tug and a small trailer to unload and load belly freight. These resources

will be released when the last K-loader is released. The servicing of belly freight requires no additional personnel and is not included in the model as belly freight is serviced in the small gaps of idle time that occur during the unloading and loading operations. Eighth, one pickup truck, one 10K forklift, one aircraft supervisor, and two workers are required to load an aircraft at the hot spot. An aircraft is loaded at the hot spot just prior to takeoff and all hazardous material requiring hot spot handling originates at WPAFB. All the assumptions in this paragraph are based on actual observation of the WPAFB air freight terminal. MHE and manpower are modeled in unlimited quantities so that the models are allowed to determine how much MHE and manpower is required to perform the operation given an expected workload and limited facilities.

Several other assumptions are not explicit in the model's design. First, all 3-level, in training, personnel are assumed to function as 5-level, fully qualified, personnel. At the time the researcher was observing the WPAFB air freight ramp operation only one personnel was in training status. Second, all 5-level personnel are assumed to be fully trained on and capable of operating all MHE available. If this is not the actual case at WPAFB or any other terminal it is a desired goal. Third, only 5-level personnel will operate MHE, and, related to this, only 7-level, supervisory, personnel will function as

supervisors. Fourth, the number of pallet positions loaded onto an aircraft equals the number of pallet positions previously removed. This was the case at WPAFB even if empty pallets had to be unloaded or loaded. All the assumptions mentioned in this section, whether paralleling reality or not, are necessary for the development of the model, and, by themselves, do not invalidate the models or their intended use.

Data

This research addresses a real world problem, and, for reasons of validity, should utilize empirical data in the development and testing of both models. The two models developed in this effort do take advantage of empirical data. The researcher observed, over the course of three weeks, the unloading and loading of 37 aircraft at WPAFB's air freight terminal. From these observations and a review of historical records, data was gathered to form the parameters, which have constant values, and the variables, which have differing values, used in these models.

Parameters. The parameters used in the models were chosen because the preponderance of the data showed little or no variation in values. Examples include the number of ramp parking spaces (5), the number of hot spot spaces (1), and the number of docks (1) available at a given time. Other examples include the number of 40K K-loaders (2), tugs (1, L-188 only), trailers (1, L-188 only), pickup

trucks (1, hot spot only), 10K forklifts (1, hot spot only), supervisors (2, one on the aircraft and one on the dock), and workers (8, three on the aircraft, three on the dock, and two in the K-loaders) used to service cargo aircraft. Remaining parameters include the average daily percentage of arriving aircraft terminating (33%), the percentage of aircraft continuing (67%), the percentage of aircraft requiring two trips to the docks (83%), the percent of aircraft requiring only one trip to the dock (17%), the percent of aircraft that are L-100s (33%), the percent of aircraft that are L-188s (67%), and the percent of aircraft requiring the use of the hot spot (11%, four out of 37 observations).

Variables. Variables are entities which can take on a number of different values. The set of all different values that an entity can take on form a distribution. The models utilize twelve variable distributions which, to some degree of confidence, mimics the distribution of values as they occur in nature. This degree of confidence was established by a six step process. First data was gathered from the real world. Second the data was ordered and a histogram was constructed. Third, the histogram was examined and a distribution with parameters was hypothesized, this formed a null hypothesis. An alternate hypothesis, which states that the distribution is something other than the one stated in the null hypothesis, was also formed. Fourth, an alpha

level of .05, a degree of confidence, was chosen for the final decision on the rejection of the null hypothesis. Fifth, a distribution goodness of fit test was chosen and conducted for nine of the twelve variable distributions. The other three distributions were assumed and not tested because of data unavailability. Appendix A contains the raw data and the goodness of fit tests for the nine tested variables.

Sixth, the result of the test was compared with the test statistic value determined by the level of significance and the null hypothesis was either rejected or not, accordingly. If the null hypothesis was not rejected it was used in the models. Note that the rejection of the null hypothesis at a certain level of significance does not mean that the level of significance for accepting the null hypothesis is the same. Determining a level of significance for accepting the null hypothesis requires a level of mathematics that is beyond the ability of this researcher. This limitation is recognized.

<u>Distributions</u>. The first distribution, used only in Model 1, is a distribution of actual aircraft arrivals around a scheduled arrival time. The data included 121 observations obtained from WPAFB's June 1986 AFLC Form 1710, Station Traffic Summary, file. The sample mean was -15.5455 minutes meaning that on average the aircraft arrive 15.5455 minutes early and the sample standard deviation was 28.7686

minutes. The data, when arranged in a histogram, appeared to be normally distributed. A chi-square goodness of fit test at the alpha equals .05 level of significance for a hypothesized normal distribution with a population mean of 16 minutes and a population standard deviation of 29 minutes was conducted. The minutes were rounded off because whole minutes are the time units used in both models. The null hypothesis was not rejected. In Model 1, consequently, actual aircraft arrivals around a scheduled arrival time were modeled using six create nodes, one for each scheduled arrival time. Each create node utilized a normal distribution with a mean of -16 minutes and a standard deviation of 29 minutes to provided for the variation in actual arrival times.

The second distribution, used only in Model 2, is a distribution of aircraft arrivals in a given day. The hypothesized distribution was not tested because a particular distribution could be logically assumed. Entity arrivals within a given time period are often modeled by a poisson distribution (26:182; 29:31). However, SLAM II requires a time between arrivals or a distribution of interarrival times for the generation of entities. The distribution of interarrival times from a poisson distribution of arrivals is exponential (26:224,225; 29:31). On average six aircraft arrive each day at the WPAFB terminal. Model 2, therefore, generates aircraft arrivals

within the course of a day via a single create node. This create node relies on an exponential distribution of interarrival times with a mean of 240 minutes (1440 minutes per day divided by six arrivals per day) to provide for the variation in arrival times.

The third distribution, used in both models, is a distribution of aircraft parking, blocking, and refueling times. The 37 data points were obtained from direct observation of WPAFB's ramp operations from 2 through 19 July 1986. The sample mean was 13.0811 minutes, the sample standard deviation was 6.7098 minutes, the low value was 2 minutes, and the high value was 24 minutes. The data, when arranged in a histogram, appeared to be uniformly distributed. A chi-square goodness of fit test at the alpha equals .05 level of significance for a hypothesized uniform distribution with a population low of 2 minutes and a population high of 24 minutes was conducted. The null hypothesis was not rejected. In both models, consequently, the time to park, block, and refuel an aircraft was modeled using a regular activity. This activity has a duration uniformly distributed from 2 through 24 minutes in order to provide for the variation in actual parking, blocking, and refueling times.

The fourth distribution, used in both models, is a distribution of the time to load a 40K K-loader at the dock. The 63 data points were obtained from direct observation of

WPAFB's ramp operations from 2 through 19 July 1986. The sample mean was 15.5079 minutes, the sample standard deviation was 6.5606 minutes, the low value was 4 minutes, and the high value was 27 minutes. The data, when arranged in a histogram, appeared to be uniformly distributed. A chi-square goodness of fit test at the alpha equals .05 level of significance for a hypothesized uniform distribution with a population low of 4 minutes and a population high of 27 minutes was conducted. The null hypothesis was not rejected. In both models, consequently, the time to load a 40K K-loader at the dock was modeled using a regular activity. This activity has a duration uniformly distributed from 4 through 27 minutes in order to provide for the variation in actual time to load a 40K K-loader at the dock.

The fifth distribution, used in both models, is a distribution of the time to unload a 40K K-loader at the dock. The 63 data points were obtained from direct observation of WPAFB's ramp operations from 2 through 19 July 1986. The sample mean was 9.3016 minutes, the sample standard deviation was 2.9492 minutes, the low value was 4 minutes, and the high value was 15 minutes. The data, when arranged in a histogram, appeared to be uniformly distributed. A chi-square goodness of fit test at the alpha equals .05 level of significance for a hypothesized uniform distribution with a population low of 4 minutes and a

population high of 15 minutes was conducted. The null hypothesis was not rejected. In both models, consequently, the time to unload a 40K K-loader at the dock was modeled using a regular activity. This activity had a duration uniformly distributed from 4 through 15 minutes in order to provide for the variation in the actual time to unload a 40K K-loader at the dock.

The sixth distribution, used in both models, is a distribution of times to load a 40K K-loader at an L-100 aircraft. The 22 data points were obtained from direct observation of WPAFB's ramp operations from 2 through 19 July 1986. The sample mean was 12.5454 minutes, the sample standard deviation was 3.2327 minutes, the low value was 6 minutes, and the high value was 19 minutes. The data, when arranged in a histogram, appeared to be normally distributed. A Kolmogorov - Smirnov (KS) goodness of fit test at the alpha equals .05 level of significance for a hypothesized normal distribution with a population mean of 13 minutes and a population standard deviation of 3 minutes was conducted. The KS test was conducted because the sample points were too few to use a chi-square test properly. Nonetheless, the KS test is a more powerful test than the chi-square test (18:73). The null hypothesis was not rejected. In both models, consequently, the time to load a 40K K-loader at an L-100 aircraft was modeled using a regular activity. This activity had a duration normally

distributed with a mean of 13 minutes and a standard deviation 3 minutes in order to provide for the variation in actual time to load a 40K K-loader at an L-100 aircraft.

The seventh distribution, used in both models, is a distribution of the time to unload a 40K K-loader at an L-100 aircraft. The 22 data points were obtained from direct observation of WPAFB's ramp operations from 2 through 19 July 1986. The sample mean was 15.0455 minutes, the sample standard deviation was 3.4569 minutes, the low value was 10 minutes, and the high value was 23 minutes. The data, when arranged in a histogram, appeared to be normally distributed. A KS goodness of fit test at the alpha equals .05 level of significance for a hypothesized normal distribution with a population mean of 15 minutes and a population standard deviation of 3 minutes was conducted. The null hypothesis was not rejected. In both models, consequently, the time to unload a 40K K-loader at an L-100 aircraft was modeled using a regular activity. This activity had a duration normally distributed with a mean of 15 minutes and a standard deviation of 3 minutes in order to provide for the variation in actual time to unload a 40K K-loader at an L-100 aircraft.

The eighth distribution, used in both models, is a distribution of the time to load a 40K K-loader at an L-188 aircraft. The 41 data points were obtained from direct observation of WPAFB's ramp operations from 2 through 19

July 1986. The sample mean was 17.8049 minutes, the sample standard deviation was 3.7028 minutes, the low value was 11 minutes, and the high value was 27 minutes. The data, when arranged in a histogram, appeared to be normally distributed. A KS goodness of fit test at the alpha equals .05 level of significance for a hypothesized normal distribution with a population mean of 18 minutes and a standard deviation of 4 minutes was conducted. The null hypothesis was not rejected. In both models, consequently, the time to load a 40K K-loader at an L-188 aircraft was modeled using a regular activity. This activity had a duration normally distributed with a mean of 18 minutes and a standard deviation of 4 minutes in order to provide for the variation in the actual time to load a 40K K-loader at an L-188 aircraft.

The ninth distribution, used in both models, is a distribution of the time to unload a 40K K-loader at an L-188 aircraft. The 41 data points were obtained from direct observation of WPAFB's ramp operations from 2 through 19 July 1986. The sample mean was 20.3902 minutes, the sample standard deviation was 4.2537 minutes, the low value was 12 minutes, and the high value was 30 minutes. The data, when arranged in a histogram, appeared to be normally distributed. A KS goodness of fit test at the alpha equals .05 level of significance for a hypothesized normal distribution with a population mean of 20 minutes and a

population standard deviation of 4 minutes was conducted. The null hypothesis was not rejected. In both models, consequently, the time to unload a 40K K-loader at an L-188 aircraft was modeled using a regular activity. This activity had a duration normally distributed with a mean of 20 minutes and a standard deviation of 4 minutes in order to provide for the variation in the actual time to unload a 40K K-loader at an L-188 aircraft.

The tenth distribution, used in both models, is a distribution of the time to prepare a aircraft for takeoff. The 37 data points were obtained from direct observation of WPAFB's ramp operations from 2 through 19 July 1986. The sample mean was 13.5135 minutes, the sample standard deviation was 4.5008 minutes, the low value was 5 minutes, and the high value was 22 minutes. The data, when arranged in a histogram, appeared to be uniformly distributed. A chi-square goodness of fit test at the alpha equals .05 level of significance for a hypothesized uniform distribution with a population low of 5 minutes and a population high of 22 minutes was conducted. The null hypothesis was not rejected. In both models, consequently, the time to prepare an aircraft for takeoff was modeled using a regular activity. This activity had a duration uniformly distributed from 5 through 22 minutes in order to provide for the variation in the time prepare an aircraft for takeoff.

The eleventh distribution, used in both models, is a distribution of the time to load an aircraft at the hot spot. The 4 data points were obtained from direct observation of WPAFB's ramp operations from 2 through 19 July 1986. The four data points varying from 18 to 36 minutes proved to be insufficient to conduct a goodness of fit test. Therefore, a uniform distribution with a low of 18 minutes and a high of 36 minutes was used to model the time to load an aircraft at the hot spot.

The twelfth distribution, used in both models, is a distribution of the time a terminating aircraft waits between unloading and loading. The 4 data points were obtained from direct observation of WPAFB's ramp operations from 2 through 19 July 1986. The four data points varying from 455 to 652 minutes proved to be insufficient to conduct a goodness of fit test. Therefore, a uniform distribution with a low of 455 minutes and a high of 652 minutes was used to model the time a terminating aircraft waits between unloading and loading.

Model Design

Both models are designed as a network of nodes connected by activities. The nodes represent resources, the creation of arriving aircraft, the assignment of aircraft attributes, and the queueing and selective servicing of aircraft according to the available ground time. The nodes also represent the acquisition and freeing of resources, and

the terminating of aircraft entities. Some activities have zero duration in which case they are used as node connectors or as branch designators; that is, they route the aircraft to the proper location in the models based on the aircraft's attributes. Some activities have variable duration and they represent the actual parking, unloading, loading, and takeoff operations. This section will describe both models in detail. A schematic of the models is contained in Appendix B and a program listing is contained in Appendix C.

Program Control Statements. The initial program control statements, which are identical in both models, perform five functions. First, the GENERAL statement provides for a programer name, project title, date, and output formats. Second, the LIMITS statement defines the maximum number of files where entities (aircraft) can be stored, the maximum number of attributes assigned to each entity, and the maximum number of entities that can exist in the model at the same time. Third, the PRIORITY statement lists the queue selection discipline for the only queue in the model. Specifically, aircraft are selected from the queue based on available ground time; that is, on the lowest value of attribute six, ground time available. Fourth, the INITIALIZE and MONITOR statements establish the length of the simulation and the intermediate and final reporting of simulation results. Fifth, the NETWORK statement marks the beginning of the simulation network.

Resources. The RESOURCE statements, which are identical in both models, perform three functions. First, they create and label a type of resource. Second, they establish the maximum number of resources available. And, third, they list AWAIT node file numbers associated with those resources. There are ten resources used in these models. These resources are used to control work flow, define limited facilities, and provide unlimited MHE and manpower. The first resource, the WORK resource, is not an actual resource but the means of limiting unloading and loading operations to one aircraft at a time. Consequently, there is only one WORK resource available. Likewise, the AIRC resource limits the unloading and loading activities on the aircraft by not allowing concurrent unloading or loading by two crews. Again, there is only one AIRC resource available.

The PARK, HTPT, and DOCK resources provide for the availability of ramp facilities. Respectively, there are five parking spaces, one hot spot, and one dock available for the operation. The KL40, FLPU, TUGS, MP70, and MP50 RESOURCE statements represent MHE and manpower resources. They are available in unconstrained amounts so that the MHE and manpower required vis-a-vis the expected workload, the arriving aircraft types, and available facilities can be determined. These resources are not actually constrained because SLAM II requires an available amount. Therefore,

excessive amounts were used. Respectively, there are 50 40K K-loaders, 50 10K forklift and pickup truck combinations, 50 tug and trailer combinations, 100 supervisors, and 400 workers available. The 10K forklift and pickup truck combination represents the extra equipment used to load the aircraft at the hot spot. They were combined together to limit the number of files required in the program. Likewise, tug and trailers, used to unload and load the L-188 aircraft, were combined.

Aircraft Creation. Aircraft creation is the only part of the two models that differ. Model 1 uses six create nodes to generate aircraft arrivals and Model 2 uses one. Most previous air freight terminal models have created aircraft arrivals utilizing only one create node (6; 10; 13; 33; 39; 40) This is applicable when the aerial port is large and the number of arriving aircraft is sizeable or evenly distributed throughout the day. However, when the aerial port is small and the number of arriving aircraft is also small or not evenly distributed throughout the day then a single create node with a single distribution function may not adequately model aircraft arrivals. Therefore, two models have been developed and their results will be compared with empirical data. Because of WPAFB's workload characteristics Model 1 with its six create nodes should predict MHE and manpower requirements better than Model 2 which under other conditions could be the better predictor.

Starting with Model 1 each create node represents a scheduled aircraft mission. See Figure 1. More specifically, each mission is scheduled to arrive at the same time each day. The CREATE statement, therefore, creates arrivals approximately every 1440 minutes (one day). Actual arrival times fluctuate around the mean arrival time via a normal distribution with a standard deviation of 29 minutes. The mean arrival time is the scheduled arrival plus the calculated mean of actual arrival times, which is -16 minutes. The CREATE statement then assigns the time of creation to attribute one, limits the number of aircraft created at this node to 25, and allows for only one branch to be taken.

Following each CREATE statement is an ASSIGN statement. The ASSIGN statement assign values to attributes two through six. Attribute two is the aircraft type; 1 for L-100 aircraft, 2 for L-188 aircraft. Attribute three is the number of pallets positions to be unloaded. Note that, the number to be loaded is assumed to equal the number unloaded. This was based on observation; however, if such was not the case then a new attribute could have been created and used to properly route the aircraft within the model. Attribute four generates a random number from zero to 100. It is used to determine if the aircraft requires the use of the hot spot (11%) or not (89%). Attribute five is an indicator of whether the aircraft is continuing or terminating; 1 for

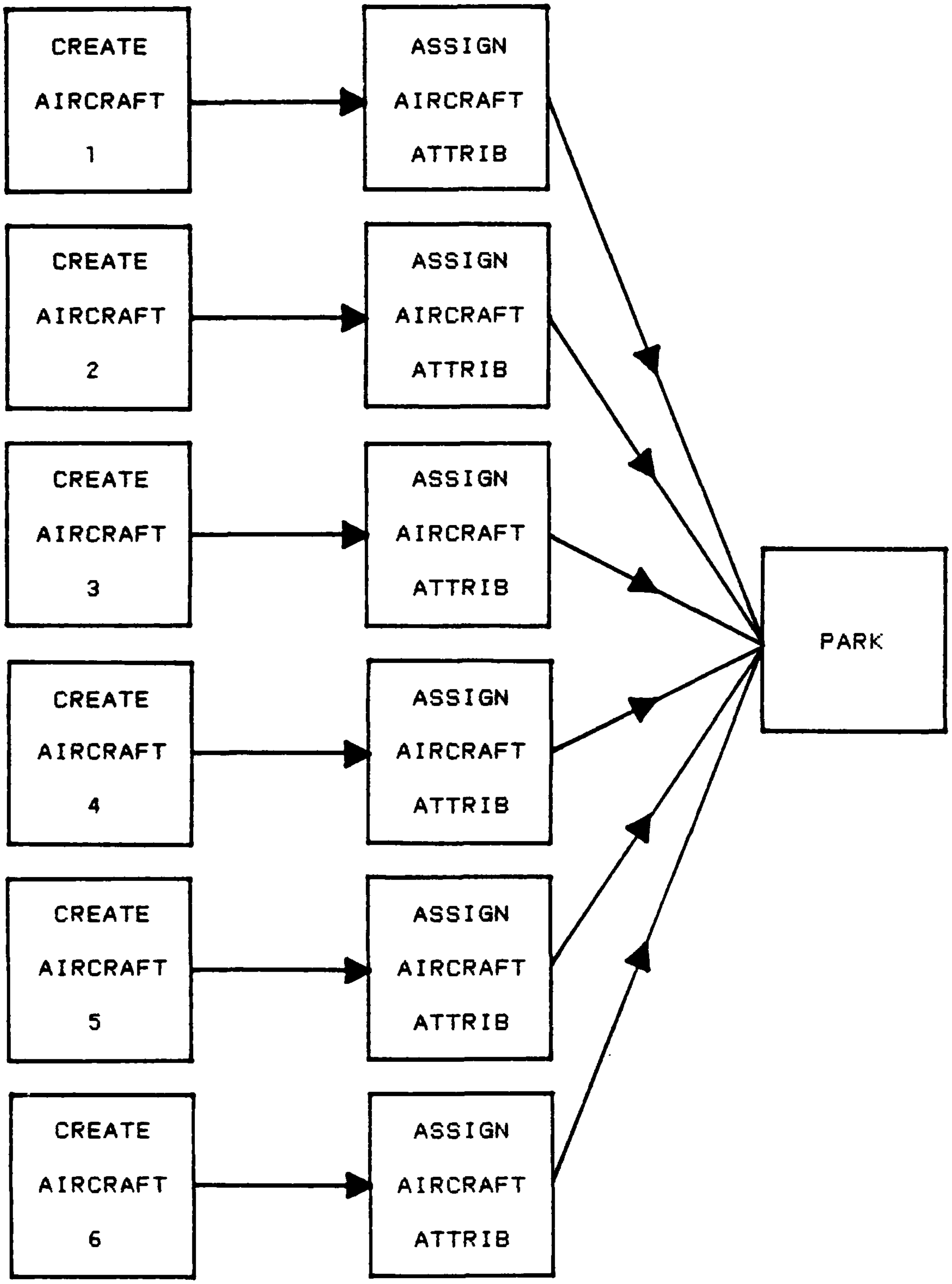


Figure 1. Aircraft Creation Model 1

continuing and 2 for terminating. Attribute six is the number of minutes the aircraft is scheduled to be on the ground. Following each ASSIGN statement is an ACTIVITY statement which routes the newly created aircraft to the parking activity.

Model 2 has a single CREATE statement which generates, on average, six aircraft arrivals per day. See Figure 2. The time between arrivals is exponentially distributed with a mean of 240 minutes. As stated previously, the mean was observed and the distribution was assumed. Like the CREATE statements in Model 1, Model 2's CREATE statement assigns the time of creation to attribute one and limits the number of aircraft to be created to 150. Following the CREATE statement attribute seven, mission type, is assigned a random value from 0 to 90. The value of attribute seven is then tested by a series of ACTIVITY statements which route the newly created aircraft to one of five ASSIGN statements. Each ASSIGN statement assigns one of the five different attributes sets that exists in Model 1. Note that the attribute sets for the two L-100 aircraft are identical in Model 1. Again, each ASSIGN statement is followed by an ACTIVITY statement which routes the aircraft to the parking activity.

Parking, Queueing, and Selection. At the parking node all aircraft await a parking place via an AWAIT statement. Once a parking place is available the aircraft's parking,

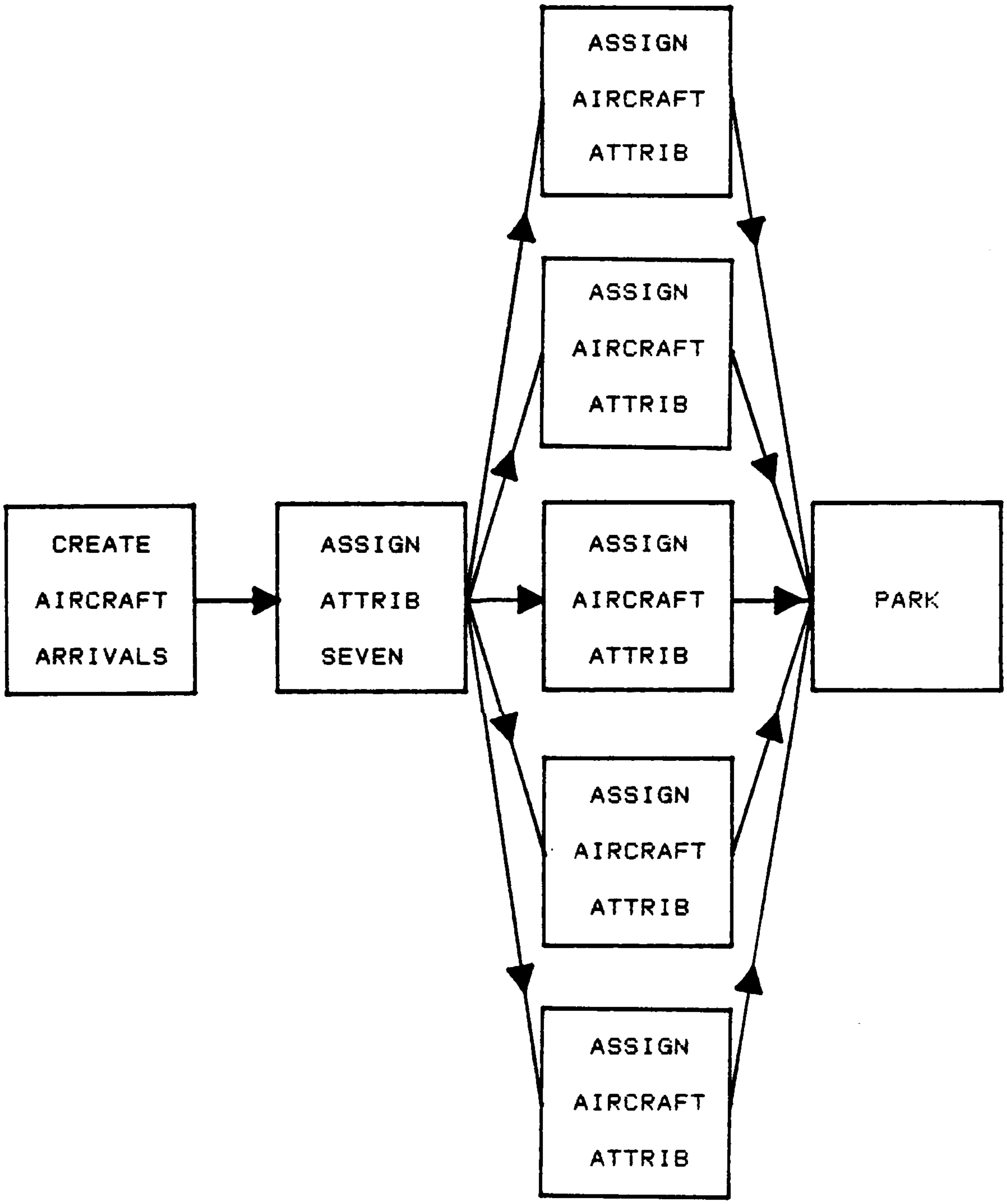


FIGURE 2. Aircraft Creation Model 2

blocking, and refueling time is modeled via and ACTIVITY statement with a duration uniformly distributed from 2 to 24 minutes. Next, all aircraft go into a queue where they are ordered according to lowest value of attribute six, available ground time. Once released from the queue the aircraft's second attribute, aircraft type, is tested via two ACTIVITY statements. The aircraft are then routed to their proper place within the network.

Aircraft Unloading and Loading. At this point the aircraft are serviced, that is, unloaded and loaded, to the point where further branching is required. For each aircraft type there is an initial set of common activities that takes place until load attributes dictate a varying sets of activities. At the WPAFB air freight ramp the common activities for the L-100 aircraft are extensive; splitting just before the last 40K K-loader is unloaded onto the aircraft and the aircraft either goes to the hot spot or prepares to takeoff immediately. The L-188, on the other hand, has only one common activity; the loading of the first 40K K-loader at the aircraft. From that point the set of service activities depends on the remaining number of 40K K-loaders to be loaded at the aircraft, whether the aircraft is continuing or terminating, and whether the aircraft requires the hot spot or not. There are eight separate routes through which an aircraft can be serviced in these models. For the brevity's sake only the most complex route

will be described in detail below. Figure 3 shows the steps modeled in servicing a terminating L-188 aircraft requiring hot spot loading. This is the most complex route in the model. An understanding of the other routes can be obtained by examining the code in Appendix C and crossreferencing it to this section.

The most complex route involves a terminating L-188 aircraft requiring two 40K K-loader loads to unload and load and the hot spot. After testing for aircraft type the entity arrives at the L-188 branch because attribute two identifies the entity as an L-188. It then proceeds through the common activity. It awaits one aircraft, two 40K K-loaders, one tug and trailer set, one aircraft supervisor, and five worker resources. Two of the workers drive the K-loaders. The first K-loader load is then removed from the aircraft. This activity has a duration which is normally distributed with a mean of 18 minutes and a standard deviation of 4 minutes. Note that only the activities are diagramed in Figure 3. Each activity is proceeded by AWAIT nodes and followed by FREE nodes as appropriate. After this activity is accomplished the aircraft resource is freed to allow the removal of the second load.

There are no more common activities at this point and the aircraft is branched according to attributes three, five, and four, respectively. Because this aircraft mission requires the removal of one more 40K K-loader load, is

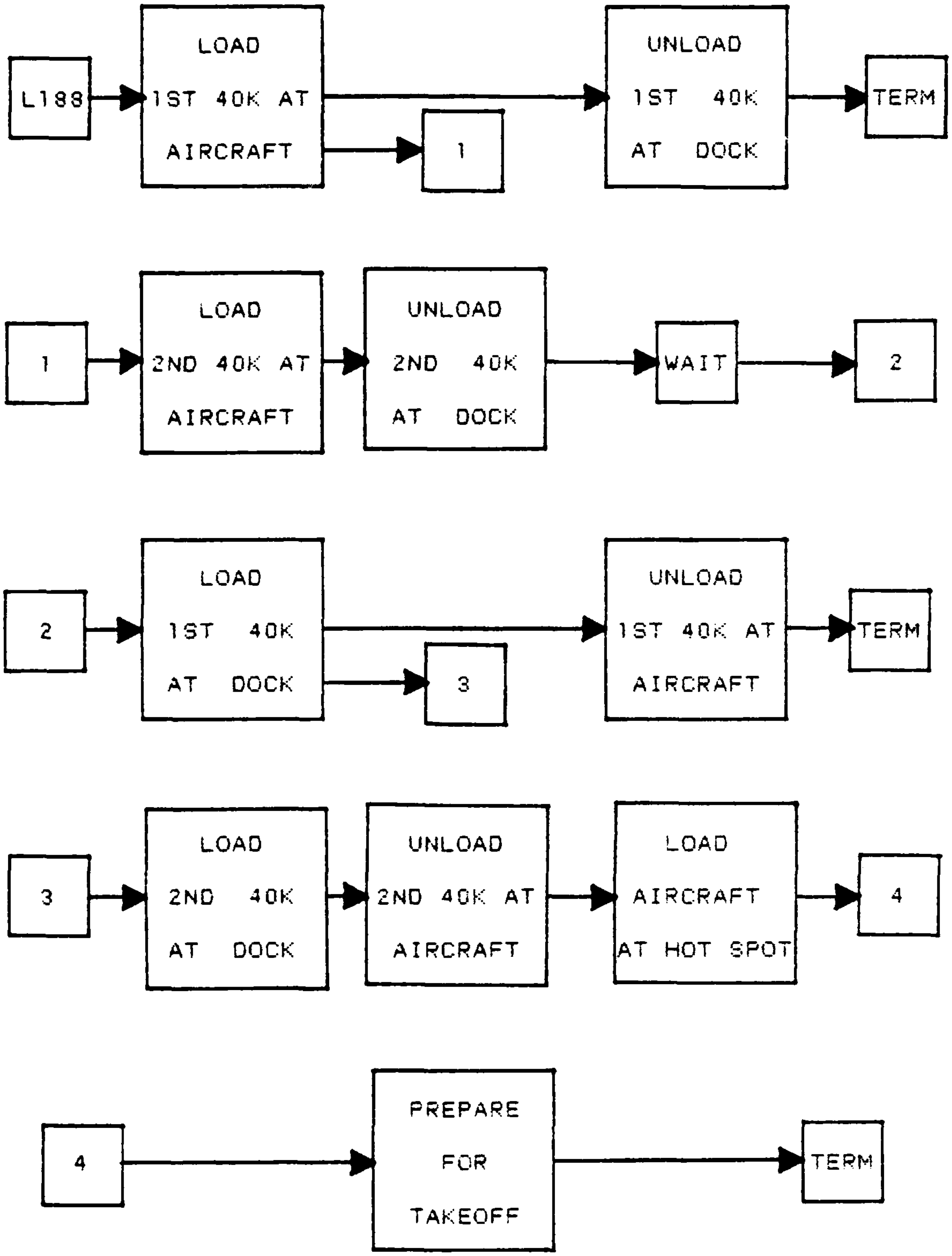


FIGURE 3. Servicing An L-188

terminating, and requires the use of the hot spot it is branched to a section of the program which has the appropriate set of activities to satisfy the aircraft's requirements. This branching is accomplished through a series of ACTIVITY statements which test the three attributes. These activities, of course, have zero duration.

After arriving at this next branch the aircraft is split into two entities to allow work to be concurrently performed on the aircraft and on the dock. The first K-loader load leaves the aircraft and awaits an empty dock, a dock supervisor, and three workers. The K-loader is unloaded via an ACTIVITY statement with a duration that is uniformly distributed from 4 through 15 minutes. After the K-loader is unloaded, the dock, the dock supervisor, the three workers, the K-loader driver, and the K-loader are freed. This first aircraft entity is terminated at this time.

The second aircraft entity continues to be serviced as the first entity sees to the unloading of the first K-loader load. After the first K-loader leaves the aircraft the aircraft resource is reacquired, the second K-loader load is removed, and the aircraft, the aircraft supervisor, and the three workers are freed. The second K-loader leaves the aircraft and awaits an empty dock, a dock supervisor, and three workers. When the required resources are obtained the

second K-loader is unloaded and the dock, the dock supervisor, the three workers, the K-loader driver, the K-loader, and the tug and trailer set are freed. Note that the use of the tug and trailer is accounted for but the unloading and loading of belly freight is not modeled because the activity is of such short duration it is included in the time to unload and load a K-loader. If this was not the case, separate activities modeling the unloading and loading of belly freight would have to be included in the models. A work resource is also freed at this time to allow other aircraft to be worked.

The aircraft mission is now terminated and the aircraft must wait a specific period of time before it is loaded for the next mission. This wait is modeled via an ACTIVITY statement with a duration uniformly distributed from 455 to 652 minutes. Once this activity is accomplished two 40K K-loaders and drivers, one dock, one dock supervisor, three workers, and a tug and trailer set are acquired via AWAIT statements. The first K-loader is then loaded at the dock. This loading operation is modeled by an ACTIVITY statement with a duration uniformly distributed from 4 through 27 minutes. Next, the dock, the dock supervisor, and three workers are freed. The aircraft entity is split again to allow for concurrent aircraft and dock operations. The first entity acquires one aircraft, one aircraft supervisor, and three worker resources. The first K-loader is then

unloaded onto the aircraft. This unloading is modeled via an ACTIVITY statement with a duration normally distributed with a mean of 20 minutes and a standard deviation of 4 minutes. The aircraft, the K-loader, and the driver are then freed and the first entity is terminated.

The second entity continues by acquiring the resources necessary to load the second K-loader at the dock, by loading the second K-loader, and by freeing the dockside resources no longer required. The same sequence of actions is repeated for the unloading of the second K-loader onto the aircraft. However, all aircraft resources are not freed at this time. The aircraft supervisor and two workers along with an acquired 10K forklift and a pickup truck travel to the hot spot. When the aircraft acquires the use of the hot spot via an AWAIT statement it leaves the parking ramp and frees a parking spot.

At the hot spot the aircraft is loaded with the dangerous cargo. This activity is modeled via an ACTIVITY statement with a duration that is uniformly distributed from 18 to 36 minutes. Note that only the loading and not the unloading of aircraft at the hot spot was modeled. Unloading at the hot spot at WPAFB was not observed by this researcher. If such was not the case a sequence of actions to handle hot spot unloading would have been incorporated into the models. Lastly, all the resources are freed and the aircraft prepares for takeoff. The takeoff preparation

was modeled via an ACTIVITY statement with a duration uniformly distributed from 5 through 22 minutes. After this preparation is completed aircraft takes off and the second entity is terminated.

Summation. In review, both models, with the exception of aircraft creation, are designed and function alike. Several control statements precede both models and establishes the simulations' parameters. The network starts out by a defining available resources. It then creates arriving aircraft, parks them, selects the one with the least available ground time, and routes it through the proper sequence of activities in order to unload and load the aircraft. The network is then closed and the results of the simulation are printed.

Model Validation Techniques

The research problem has been presented and two models to solve it have been developed. However, the ability of the models to predict the MHE and manpower requirements of an air freight ramp operation must be tested and confidence in the models must be established. There are two levels of validation that must be addressed in order to secure any reasonable level of confidence in the models' utility. Both the models' face validity and output validity must be determined.

First, the face validity of the model must be determined, that is, the model must be verified before it is

validated (35:30). This verification is accomplished by checking the models' structure and results for reasonableness. Model structure includes the assumptions of the model and how it represents the air freight ramp operation. Model results are the outputs generated when data is fed into the model and all subroutines of the model are exercised. People familiar with the an air freight ramp operation are in an excellent position to determine the reasonableness of the model's structure. Therefore, the model's structure was examined by the 2750 ABW's assistant air terminal manager (ATM) and several shift managers. This examination relied on structured interviews detailing the design and assumptions of the models. The results of these interviews is contained in Appendix D. Data exercising all of the models' subroutines were fed into the models to identify programs flaws. The results of these actions are the topic of the next chapter.

Next, the model's input - output transformations must be tested (35:30-31). This goes beyond determining reasonableness; it determines how well the model performs. Comparing model outputs with real data while keeping the inputs constant is one method of validating the performance of the model. Specifically, both models determine the number of 40K K-loaders and manpower required to conduct WPAFB's air freight ramp operation throughout the course of a day. These requirements, in effect, form a distribution

over time. These resource requirement distributions were compared with the distribution of actual 40K K-loaders and manpower used by WPAFB's air freight ramp operation. First, a sample of twenty days data on the resources required to conduct the operation at six randomly chosen times throughout the day were selected from each model and WPAFB'S air freight ramp operation. Normal distributions for all three samples cannot be assumed, therefore, nonparametric tests such as the Mann - Whitney U test were used to determine if the three samples are drawn from the same population (36:Chap 15).

Summary

This chapter described and explained the methodology used to develop and validate the two SLAM II simulation models. The various sections of this chapter provided a description of the WPAFB air freight ramp operation, the models' assumptions, the data used to develop the model, the models themselves, and the various techniques that will be used to verify and validate the models. The results of the model validation process is the topic of the next chapter.

IV. Model Validation

The techniques employed to validate both models are examined in this chapter. Specifically, validating the models involved establishing face validity and output validity. The establishment of face validity, also called verification, centered around two primary tasks; debugging the simulation models and establishing the degree to which the models represent reality. Output validation, on the other hand, centered on comparing the MHE and manpower required by the models with the MHE and manpower required by WPAFB's air freight ramp operation. Validating the output, therefore, established the degree to which the models mimic the reality they represent. A summary reemphasizing the major results of model verification and validation concludes this chapter.

Verification

Verification of the models required extensive debugging. At first the models included numerous syntactical errors which were ultimately eliminated through multiple revisions of both models. Nonetheless, neither model produced a useable output; semantic errors emerged. In order to solve these semantic errors all activities were given activity numbers and durations so that the flow of entities could be traced through the programs. Aircraft attributes where also changed so that all parts of both

models could be thoroughly exercised. The use of the TRACE option with the MONITOR statement proved an invaluable tool in locating semantic errors. The three most common semantical errors involved the branching of entities to their proper place in the simulation models, the splitting of a single entity into two separate entities to allow for concurrent operations, and the failure to free resources previously allocated. In all, fifty five revisions were required to eliminate all syntactical and semantical errors.

Outputs of both models were then examined for reasonableness. No extraordinary values for the utilization of facilities, MHE, or manpower were noted. Aircraft arrivals also provided a realistic workload. Lastly, model activity service times reflected the observed service times. However, a less bias and more expert opinion on the degree to which the models represent the reality of the WPAFB air freight ramp operation was sought. This opinion was acquired by interviewing supervisory personnel at the WPAFB air freight terminal. Because the interviews were voluntary only four personnel responded. However the four personnel represented the entire range of supervision at the terminal. The assistant air terminal manager, one shift manager, one assistant shift manager, and one foreman were interviewed.

The interviews were presented by this researcher as structured explanations of the assumptions, the designs, and the outputs of the two SLAM II simulation models. In these

interviews nineteen separate topics addressing various model assumptions, designs, and outputs were explained using the previous chapter and the simulation outputs as guides. The respondents were then asked to rate the "reasonableness" of each topic. The range of available responses included "very unreasonable", "slightly unreasonable", "slightly reasonable", and "very reasonable". Reasonableness, in this context, meant the degree to which each of the areas reflected or represented the reality of the WPAFB air freight ramp operation.

The complete responses, which, at best, reflect an ordinal measurement of the face validity, are recorded in Appendix D. The responses, though, were favorable. None of the topics were rated very or slightly unreasonable by any respondent. At the other end of the spectrum all four respondents rated fourteen of the topical areas very reasonable. Three of the topical areas were rated very reasonable by three respondents and slightly reasonable by one. All three being objected to by different respondents. The objections raised in these three cases included the neglect of navy reserve personnel, the nearly limitless aircraft parking available elsewhere on the base, and the occasional use of a 40K K-loader at the hot spot. However, these factors did not affect the reasonableness of the models in any significant way as testified by the three remaining respondents.

Two of the topical areas were rated slightly reasonable by three respondents and very reasonable by one. The objections in these two cases included the aircraft creation process in Model 2 and the hot spot loading process. Aircraft creation in Model 2 involves a single create node utilizing a time between creation distribution to generate, on average, six aircraft a day. Because the WPAFB air freight ramp workload follows the LOGAIR scheduled very closely they viewed the Model 1 aircraft creation process as more realistic than Model 2. The respondents, however, recognized the utility of such an aircraft creation process in modeling a larger port. The second objection concern the failure to model the unloading of cargo at the hot spot. This activity was not observed by the researcher and constitutes an inadequacy in the models. The relative frequency of requiring such an activity was estimated to range from 1% to 3% of all arriving aircraft by the respondents. Because of the infrequency of this activity the respondents did not feel that reality was significantly misrepresented in the models. Overall, debugging the models, manipulating aircraft attributes in order to exercise all parts of both models, and the examining of the assumptions, designs, and outputs of the models by the researcher and personnel familiar with the WPAFB air freight ramp operation led to a subjective level of confidence in the face validity of both models.

Validation

Validation of model outputs was much less subjective than establishing face validity. A specific procedure was developed and carried out in order to compare the models' ability to determine the MHE and resources required to perform the air freight ramp operation with the MHE and manpower actually used by the terminal. This procedure involved six different steps. First, an assumption about the use of MHE and manpower throughout a given day was made. It was assumed that MHE and manpower utilization through time could be described by a distribution. If such was the case, it could be possible to compare the resource utilization distributions of both models with each other and with a resource utilization distribution of the actual ramp operation.

Second, MHE and manpower utilization distributions had to be obtained. Though the dependent variable, the number of resources in use, is discrete, the independent variable, time, is continuous. To obtain enough data to form such a distribution would have required more time and data than either the researcher or terminal personnel could afford to spend or collect, respectively. Instead of forming the entire distribution through time, sections of the the distribution would be formed. That is, enough data would be collected to form a utilization distribution of a specific resource for a specific time. The number of times for which

the data was to be collected was subjectively chosen by the researcher; specifically six. The actual times for which data was collected was determined randomly. A computer program was written to randomly produce times on a twenty four hour clock. The program also randomly chose a starting point for selecting the times. In the end, data on resource utilization were collected at 01:53, 03:19, 07:14, 15:16, 16:21, and 17:10 hours. Because the use of no more than one tug, trailer, pick-up truck, or 10K forklift on the ramp or hot spot was envisioned and because the requirements for their use occurred only when an L-188 was being serviced utilization data was not collected on them. Utilization data was collected on 40K K-loaders, supervisors, and workers only.

Third, the data had to be collected or generated. Data on actual ramp utilization of 40K K-loaders, supervisors, and workers were collected by the WPAFB air freight terminal shift managers from 29 July 1986 to 15 August 1986. The shift managers recorded the utilization of these ramp resources at the six specified times each day. Data for Sundays and Mondays was ignored as the terminal had only five scheduled flights on those days. In all, data for fourteen days were collected. This data was crosschecked against aircraft arrival and departure data maintained by the terminal and contained on AFLC Form 1710, Daily Traffic Summary, for reasonableness. No problems with the shift

managers accurately recording resource use were identified.

Model data also had to be generated. This was a simple task as SLAM II allows you to stop the simulation at any time and obtain intermediate results on current resource utilization. Each model ran a twenty one day simulation stopping once each day at one of the preselected times. Therefore, twelve simulations were conducted. The statistics were cleared after the first 24 hours and the second 24 hours were ignored to avoid start up anomalies. Data from days three through sixteen were recorded for comparison with the other data distributions. Maximum, average, and standardized resource utilization figures could now be computed and compared. Table I, below, presents the maximum utilization encountered for each resource.

TABLE I

Maximum Resource Utilization

RESOURCE TYPE	UTILIZATION ON RAMP	UTILIZATION IN MODEL 1	UTILIZATION IN MODEL 2
40K K-LOADERS	3	2	2
SUPERVISORS	2	2	2
WORKERS	8	8	8

Note that maximum utilization is equal in all in instances except for an additional K-loader. One additional K-loader was used on one occasion when another K-loader had a temporary mechanical problem. Average utilization, presented in Table II below, was also very similar between the two models and the ramp.

TABLE II

Average Resource Utilization

RESOURCE TYPE	UTILIZATION ON RAMP	UTILIZATION IN MODEL 1	UTILIZATION IN MODEL 2
40K K-LOADERS	0.910	0.610	0.640
SUPERVISORS	0.730	0.550	0.570
WORKERS	2.950	2.210	2.330

Note that there seems to be a difference between the average utilization of resources on the ramp and the average utilization of resources as presented by either model. The average utilization of resources on the ramp was computed from data based on observations of the ramp at the six specific times. At these times the ramp, as a whole, was being utilized 52.4% of the time. Average resource utilization from the models, however, reflected utilization throughout the day and not just at the six specified times. In the models the ramp was utilized 36.5% of the time. The

difference is attributed to the fact that the randomly chosen observation times occurred at busier times in the day. In fact, if the resource utilization rates are standardized by dividing each utilization rate by the number of percentage points that the ramp is utilized the differences diminish considerably. Do not confuse this standardization of resource utilization rates with the common use of the term "standardize" which refers to division by the standard deviation. Table III presents the results of standardizing resource utilization rates.

TABLE III

Standardized Resource Utilization Rates

RESOURCE TYPE	UTILIZATION ON RAMP	UTILIZATION IN MODEL 1	UTILIZATION IN MODEL 2
40K K-LOADERS	0.017	0.017	0.017
SUPERVISORS	0.014	0.015	0.016
WORKERS	0.057	0.060	0.064

The maximum, average, and standardized resource utilization rates are indeed similar and there are several statistical tests that could be used to identify just how similar the utilization rates really are given a level of confidence. However, this cannot determine if the three resource utilization distributions are the same for each

resource type. Multiple sample statistical tests must be accomplished before conclusions about the resource utilization distributions can be formed. The test used was the Mann - Whitney U Test. The Mann - Whitney U test was chosen because an assumption concerning the normality of the distributions, crucial to the use of parametric tests, was not accepted by the researcher. Specifically, the units of measure; that is the number of resources in use, is discrete. More importantly, ramp resources tend to be used in sets; for example, two 40K K-loaders, one supervisor, and five workers are almost always used to unload or load a LOGAIR aircraft at WPAFB. For these two reasons the distribution of resource use was assumed to be other than normal and a nonparametric test was used.

While there are several nonparametric techniques that can test for equivalence among three or more distributions, pair-wise comparisons provide more definitive conclusions. The Mann - Whitney U Test is just such a test. Resource utilization data collected on the ramp or generated by the models formed the samples to be compared. For each of three resources, K-loaders, supervisors, and workers, and for each of six different observation times, three pair-wise tests for equivalent distributions were made. The first test compared the ramp data with the data from Model 1. The second test compared the ramp data with the data from Model 2. The third test compared Model 1 data with Model 2 data.

In all, fifty four Mann - Whitney U tests were accomplished.

The null hypothesis in each test was that the two samples were obtained from the same population. The alternate hypothesis was that the two samples were not drawn from the same population. The test statistic for the Mann - Whitney U Test is U. U is a measure of the cumulative ranks of all the elements in a single sample when combined with the second sample. If the two samples are drawn from the same population then probability theory tells us that their U statistics should be relatively similar. The probability that one statistic is x units smaller than the other for specific sample sizes is known. Consequently, in comparing any of the fifty four pairs of samples, with each combined sample having twenty eight elements, at the 95% confidence level the null hypothesis must be rejected if the smaller U statistic is less than 55 (36:276). Table IV presents the U statistics for each of the 54 tests.

Out of the 54 tests the null hypothesis could not be rejected 51 times; that is, there is insufficient proof at the 95% confidence level that the resource utilization samples were drawn from different populations. In short, in 94.4% of the cases the was no significant difference at the 95% confidence level between the resource utilization distributions of either model and the ramp or between both models. If, in reality, there was no difference in the distributions the 5.4% acceptance rate for the alternate

TABLE IV

U Statistics for Pair-wise Combinations

	40K	K-LOADERS		SUPERVISORS			WORKERS		
TIME	RAMP MOD1	RAMP MOD2	MOD1 MOD2	RAMP MOD1	RAMP MOD2	MOD1 MOD2	RAMP MOD1	RAMP MOD2	MOD1 MOD2
0153	81.0	81.0	98.0	92.0	94.0	97.0	95.0	97.0	96.0
0319	78.5	98.0	78.5	87.0	88.0	94.0	77.5	89.0	92.5
0714	97.5	84.5	83.0	84.0	84.0	98.0	85.5	85.5	94.0
1516	87.0	61.5	63.0	88.5	53.0	66.0	84.0	53.5	56.5
1621	68.0	55.0	61.5	84.0	60.0	65.0	78.0	67.5	67.0
1710	96.0	94.5	97.0	95.0	87.5	86.0	93.0	86.5	92.0
AVE.	84.7	79.1	80.2	88.4	77.8	84.3	85.5	79.5	83.0

hypothesis is reasonable when there is a 5% chance of committing a Type I error; that is, rejecting the null hypothesis when it is true. However, it can not be concluded that a particular model is a good predictor of ramp resource requirements until a confidence interval for the mean U is established. The same situation applies to the question of whether either model is a good predictor of of the use of a particular resource. Confidence intervals for the mean U of all pair-wise comparisons that deal with comparing model resource use to ramp resource use are required. In this case the Central Limit Theorem allows the use of parametric statistical techniques such as small

sample confidence interval using student's t distribution. Table V below clarifies these statements by presenting statistics on various aggregations of the U statistics.

It is apparent that the 95% confidence intervals for the mean U statistics listed above do not enter into the rejection region for the null hypothesis. Based on these statistics and at the 95% confidence level Model 1 and Model 2 are good predictors of 40K K-loader, supervisor, and worker use on the WPAFB air freight ramp. The same can be said of each model when addressing only one resource. Furthermore, the differences in the ability to predict ramp resource requirements between the two models can be tested by using a small sample test on the difference between the two population means using the student's t distribution. Four tests comparing the means between both models for each of the four categories of aggregation listed in Table V was conducted. The null hypotheses state that the means for both models are equal. Because the mean for Model 1 was always larger and the standard deviation always smaller than those for Model 2, the alternate hypothesis for each test is that Model 1's mean is larger than Model 2's. Consequently, the null hypothesis was be rejected at the 95% confidence level when comparing the mean U's for both models; therefore, Model 1 is a better predictor of resource use than Model 2. Opposingly, the null hypotheses for comparing both models for a particular resource; that is 40K

TABLE V

Statistics on Aggregations of U

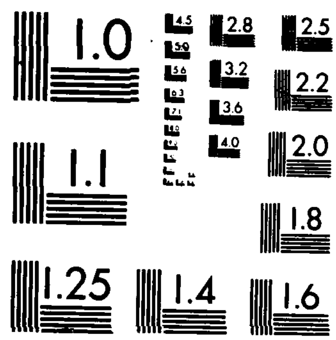
AGGREGATION TYPE	MEAN U	STANDARD DEVIATION	95% CONFIDENCE INTERVAL
Ramp-Model 1	86.19	7.82	82.30 - 90.08
Ramp-Model 2	78.78	15.79	70.93 - 86.63
40K Model 1	84.67	11.20	72.91 - 96.43
40K Model 2	79.08	17.42	60.80 - 97.36
Suprv. Mod 1	88.42	4.41	83.79 - 93.05
Suprv. Mod 2	77.75	16.92	59.99 - 95.51
Workr. Mod 1	85.50	7.33	77.81 - 93.19
Workr. Mod 2	78.50	17.06	60.59 - 96.41

K-loaders, or supervisors, or workers, was not rejected in any case. Model 1 is not a better predictor of 40K K-loaders, or supervisors, or workers than Model 2. For these tests sample size was probably the limiting factor in the failure to reject the null hypotheses.

Summation

This chapter explained the techniques use to verify and validate the models. It was concluded that both models had sufficient face validity albeit that conclusion was based on subjective tests. Next, the resources required to perform the air freight ramp operation at WPAFB were successfully

AD-A174 430 ESTIMATING MATERIAL HANDLING EQUIPMENT (MHE) AND 2/2
MANPOWER REQUIREMENTS FO (U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF SYST M R FREDETTE
UNCLASSIFIED SEP 86 AFIT/GLM/LSM/86S-24 F/G 15/5 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

predicted by both models at the 95% level of confidence. Furthermore, Model 1 was a better predictor of resource use than Model 2 when all resources were aggregated; however, such was not the case when each resource was looked at individually. In summation, both models predicted resource requirements successfully with Model 1 outperforming Model 2.

V. Summary

An existing Air Force problem has been identified, solution oriented research justified, and models developed and validated. All that remains is a discussion of the results, limitations, recommendations, and conclusions. Each of these topics are explored in this final chapter.

Results

This research effort developed and validated two separate models that can be used to estimate MHE and manpower resources for the WPAFB air freight ramp operation. The models, each incorporating a different aircraft creation process, determine MHE and manpower requirements by simulating the ramp operation and tapping an unlimited supply of MHE and manpower as required. The face validity of the models was verified by extensive program debugging, exercising all elements of both models with artificial data, and researcher and expert examination of the reasonableness of the models' assumptions, designs, and outputs. The outputs of both models were validated by comparing resources required for ramp operations with resources required by the simulation models. Samples of resources required to perform the ramp operation were collected from the terminal and both models. Nonparametric tests showed that the resources required by the ramp and both models were statistically equivalent at the 95% confidence level. At that same

confidence level it was determined that Model 1 was a significantly better predictor of resource requirements than Model 2.

This success was achieved by developing models that were specifically designed to determine MHE and manpower requirements by integrating a scheduled workload, various aircraft characteristics, fixed facilities, ramp activities, and an unlimited supply of MHE and manpower in order to accomplish the ramp mission. Previous requirement determination techniques and models determined MHE and manpower requirements by manipulating a limited number of variables. Moreover, MHE and manpower requirements were never related to each other. Furthermore, if previous models were used to determined MHE or manpower requirements they could do so only by successively simulating the operation using different workloads and facility values. The models resulting from this effort determine MHE and manpower requirements via a single simulation; a simulation that takes 2 seconds of central processing unit (CPU) time per day of simulation.

Limitations

The models developed here are not the solution, they are, instead, tools that can be used to develop a solution. Such a solution will be examined in the next section; however, the limitations of these models must be discussed prior to discussing their use in developing a solution to

the Air Force problem.

The primary limitation of these models is that they are not generic. They were developed for the WPAFB air freight ramp operation in order to secure empirical data for development and validation purposes. In addition, the WPAFB air freight was not functioning in a contingency environment. Applying these models directly to other air freight terminals without modifications would invalidate their utility. To develop models that are generic and applicable to a war environment a more extensive data collection effort must be undertaken. Lastly, MHE and manpower requirement determination is an important issue to other functions in an air freight terminal. This thesis addressed only the ramp operation as a consequence of scoping the problem to manageable size. It is evident that a more comprehensive, generic, war related model must be developed. This thesis, if it does anything, offers a successful methodology for developing such a model.

There is another set of limitations apart from what the models include, specifically, the set of limitations that deal with the hardware and software used in the models. SLAM II is a powerful simulation package but there are other simulation and modeling tools on the market that may also prove useful for determining MHE and manpower requirements. Whichever software is used, it and the hardware must be able to accommodate the comprehensive,

generic, war related model envisioned. Secondly, the hardware used was in the minicomputer size range. Such a computer may not be survivable or portable enough for a contingency air freight terminal on the move. A microcomputer would be more applicable. Note that a microcomputer version of SLAM II is available from its developers. Lastly, the program must be made interactive and painless to use. These models worked because the researcher was extremely familiar with them. More sophisticated computer programming than employed in this effort and the use of multiple languages are prerequisites for an interactive, user friendly model.

Recommendations

In order to develop an accurate, timely means of determining air terminal resource requirements under all conditions a comprehensive, generic, model of an air freight terminal must be developed. Such a development requires extensive data collecting and testing in addition to commitment by the Air Force transportation community. Development and implementation of such a model could enhance the Air Force's war planning and execution capabilities. If the computer software and hardware can accommodate an even larger model then questions concerning resource utilization, and throughput capability may also be incorporated into the model. Furthermore, the model should be portable, survivable, and extremely user friendly.

Lastly, the methodology used in this thesis should be used a guide for the development of such a model. Just as in this thesis an interaction of scheduled workload, aircraft, fixed facilities , MHE, and manpower should be utilized by the proposed model to determine resource requirements. Attention should also be placed on how workload, in the form of arriving aircraft, can be modeled. In this thesis one representation of aircraft arrival produced a model that was a significantly better predictor of resource requirements than the other.

Conclusion

The Air Force has a need for an accurate, timely resource requirement determination technique for use in an air freight terminal. This thesis did not attempt to completely satisfy that need it, instead, attempted to illustrate that the necessary tools for developing a solution to the Air Force problem exists. To do so the researcher scoped the problem down significantly and developed and tested two SLAM II simulation models which attempted to predict MHE and manpower requirements for the WPAFB air freight ramp operation. Both models successfully predicted ramp MHE and manpower requirements at the 95% confidence level. Lastly, model limitations were presented and the use of the models as methodological guides for the development of a comprehensive, generic, war related resource requirement determination model was recommended.

Appendix A: Data Distributions

Distribution One

Distribution One is the distribution of aircraft arrival times around a scheduled arrival time. Actual arrivals before the scheduled time are recorded in negative numbers and actual arrivals after the scheduled time are recorded in positive numbers. Below is a stem and leaf display of the data, a set of test hypotheses, and the results of a chi-square goodness of fit test.

TABLE VI

Distribution One Data
(In Minutes)

+6	0
+5	0 0 5
+4	0 5
+3	0 0 8
+2	0 0 0 2 5 5
+1	0 0 1 5 5 5 7
+0	0 3 3 5 5 5 5 5 5 6 7 8
-0	0 0 1 5 5 5 5 5 5
-1	0 0 0 0 0 0 1 3 3 5 5 5 5 5 5 7 8
-2	0 0 0 0 0 0 0 1 2 5 5 5 5 5 5 5 5 5 7
-3	0 0 0 0 0 0 0 0 2 4 5 5 5
-4	0 0 0 0 2 2 2 5 5 5 5
-5	0 0 0 0 1 5 5 6
-6	0 0 0 5 5
-7	0 9
-8	0

Sample size equals 121.
Sample mean equals -15.5455 minutes.
Sample standard deviation equals 28.7686 minutes.
Sample low value equals -80 minutes.
Sample high value equals +60 minutes.

Null Hypothesis: The sample was drawn from a population of values normally distributed with a mean of -16 minutes and a standard deviation of 29 minutes.

Alternate Hypothesis: The sample data was not drawn from a population of values normally distributed with a mean of -16 minutes and a standard deviation of 29 minutes. Minutes are rounded to the nearest whole number in order to maintain consistency with both models.

Test: Chi-square goodness of fit with five degrees of freedom and a 95% confidence level.

Rejection Region: Reject the null hypothesis if the calculated chi-square is greater than 11.0705 (26:899).

TABLE VII

Distribution One Calculated Chi-square

Range In Z	Expected Count (E)	Observed Count (O)	$(E-O)^2/E$
+1.5 - +3.0	7.93	9.00	0.144
+1.0 - +1.5	11.12	10.00	0.133
+0.5 - +1.0	18.13	18.00	0.001
0.0 - +0.5	23.17	22.00	0.059
0.0 - -0.5	23.17	30.00	2.013
-0.5 - -1.0	18.13	16.00	0.250
-1.0 - -1.5	11.12	8.00	0.875
-1.5 - -3.0	7.93	8.00	0.001
			3.457

Test Result: Calculated chi-square less than 11.0705; do not reject the null hypothesis.

Distribution Three

Distribution Three is the distribution of aircraft parking, blocking, and refueling times. Below is a stem and leaf display of the data, a set of test hypotheses, and the results of a chi-square goodness of fit test.

TABLE VIII

Distribution Three Data
(In Minutes)

+0	2 2 3 3 4 4 5 6 8 8 9 9
+1	0 1 1 1 2 3 4 4 5 5 6 6 6 7 8 8 8 9
+2	0 1 2 3 3 4 4

Sample size equals 37.
Sample mean equals 13.0811 minutes.
Sample standard deviation equals 6.7098 minutes.
Sample low value equals 2 minutes.
Sample high value equals 24 minutes.

Null Hypothesis: The sample was drawn from a population of values uniformly distributed with a low of 2 minutes and a high of 24 minutes.

Alternate Hypothesis: The sample data was not drawn from a population of values uniformly distributed with a low of 2 minutes and a high of 24 minutes.

Test: Chi-square goodness of fit with two degrees of freedom and a 95% confidence level.

Rejection Region: Reject the null hypothesis if the calculated chi-square is greater than 5.99147 (26:899).

TABLE IX

Distribution Three Calculated Chi-square

Range In Minutes	Expected Count (E)	Observed Count (O)	$(E-O)^2/E$
2.0 - 6.5	7.57	8.00	0.026
6.5 - 10.5	6.73	5.00	0.443
10.5 - 14.5	6.73	7.00	0.011
14.5 - 18.5	6.73	9.00	0.768
18.5 - 24.0	9.25	8.00	0.169
			1.411

Test Result: Calculated chi-square less than 5.99147; do not reject the null hypothesis.

Distribution Four

Distribution Four is the distribution of times to load a 40K K-loader at a dock. Below is a stem and leaf display of the data, a set of test hypotheses, and the results of a chi-square goodness of fit test.

TABLE X

Distribution Four Data
(In Minutes)

+0	4 4 5 5 5 6 6 7 7 7 8 8 8 9
+1	0 0 0 1 1 1 1 2 2 3 3 3 3 3 4 4
+1	5 5 5 5 6 6 6 6 7 7 7 9 9 9 9
+2	0 1 1 1 1 1 2 2 3 3 3 4 4 6 6 7 7 7

Sample size equals 63.
Sample mean equals 15.5079 minutes.
Sample standard deviation equals 6.5606 minutes.
Sample low value equals 4 minutes.
Sample high value equals 27 minutes.

Null Hypothesis: The sample was drawn from a population of values uniformly distributed with a low of 4 minutes and a high of 27 minutes.

Alternate Hypothesis: The sample data was not drawn from a population of values uniformly distributed with a low of 4 minutes and a high of 27 minutes.

Test: Chi-square goodness of fit with four degrees of freedom and a 95% confidence level.

Rejection Region: Reject the null hypothesis if the calculated chi-square is greater than 9.48773 (26:899).

TABLE XI

Distribution Four Calculated Chi-square

Range In Minutes	Expected Count (E)	Observed Count (O)	$(E-O)^2/E$
4.0 - 7.5	9.59	10.00	0.018
7.5 - 10.5	8.22	7.00	0.180
10.5 - 13.5	8.22	11.00	0.943
13.5 - 16.5	8.22	10.00	0.387
16.5 - 19.5	8.22	7.00	0.180
19.5 - 22.5	8.22	8.00	0.006
22.5 - 27.0	12.33	10.00	0.439
			2.153

Test Result: Calculate chi-squared less than 9.48773; do not reject the null hypothesis.

Distribution Five

Distribution Five is the distribution of times to unload a 40K K-loader at a dock. Below is a stem and leaf display of the data, a set of test hypotheses, and the results of a chi-square goodness of fit test.

TABLE XII

Distribution Five Data
(In Minutes)

+0	4 4 4 4 5 5 5 6 6 6 6 7 7 7 7
+0	7 7 7 7 7 8 8 8 8 8 9 9 9 9 9 9 9
+1	0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1
+1	2 2 2 2 2 3 3 3 3 3 4 4 5 5 5

Sample size equals 63.
Sample mean equals 9.3016 minutes.
Sample standard deviation equals 2.9492 minutes.
Sample low value equals 4 minutes.
Sample high value equals 15 minutes.

Null Hypothesis: The sample was drawn from a population of values uniformly distributed with a low of 4 minutes and a high of 15 minutes.

Alternate Hypothesis: The sample data was not drawn from a population of values uniformly distributed with a low of 4 minutes and a high of 15 minutes.

Test: Chi-square goodness of fit with two degrees of freedom and a 95% confidence level.

Rejection Region: Reject the null hypothesis if the calculated chi-square is greater than 5.99147 (26:899).

TABLE XIII

Distribution Five Calculated Chi-square

Range In Minutes	Expected Count (E)	Observed Count (O)	$(E-O)^2/E$
4.0 - 6.5	14.32	12.00	0.375
6.5 - 8.5	11.46	14.00	0.565
8.5 - 10.5	11.46	15.00	1.097
10.5 - 12.5	11.46	12.00	0.026
12.5 - 15.0	14.32	10.00	1.302
			3.366

Test Result: Calculated chi-square less than 5.99147; do not reject the null hypothesis.

Distribution Six

Distribution Six is the distribution of times to load a 40K K-loader at an L-100 aircraft. Below is a stem and leaf display of the data, a set of test hypotheses, and the results of a Kolmogorov - Smirnov goodness of fit test. Because of the small sample size and chi-square's requirement that all cells counts be greater than or equal to five, the K-S test is used.

TABLE XIV

Distribution Six Data
(In Minutes)

+0	6 7 9 9
+1	1 1 1 1 2 2 2 3 3 3 3 4 5 5 6 6 8 9

Sample size equals 22.
Sample mean equals 12.5455 minutes.
Sample standard deviation equals 3.2327 minutes.
Sample low value equals 6 minutes.
Sample high value equals 19 minutes.

Null Hypothesis: The sample was drawn from a population of values normally distributed with a mean of 13 minutes and a standard deviation of 3 minutes.

Alternate Hypothesis: The sample data was not drawn from a population of values normally distributed with a mean of 13 minutes and a standard deviation of 3 minutes.

Test: Kolmogorov - Smirnov goodness of fit at the 95% confidence level.

Rejection Region: Reject the null hypothesis if the maximum absolute difference between the empiric cumulative distribution function and the hypothesized cumulative distribution function, know as D, is greater than 0.28995 (36:251).

TABLE XV

Distribution Six Calculated D

n	x	S(x)	Z	F(x)	|F(x) - S(x)|
1	6	0.0454	-2.33	0.0098	0.0356
2	7	0.0909	-2.00	0.0228	0.0681
3	9	0.1364	-1.33	0.0912	0.0452
4	9	0.1818	-1.33	0.0912	0.0906
5	11	0.2272	-0.67	0.2535	0.0262
6	11	0.2727	-0.67	0.2535	0.0192
7	11	0.3182	-0.67	0.2535	0.0647
8	11	0.3636	-0.67	0.2535	0.1101
9	12	0.4091	-0.33	0.3694	0.0397
10	12	0.4545	-0.33	0.3694	0.0851
11	12	0.5000	-0.33	0.3694	0.1306
12	13	0.5454	0.00	0.5000	0.0454
13	13	0.5909	0.00	0.5000	0.0909
14	13	0.6364	0.00	0.5000	0.1364
15	13	0.6818	0.00	0.5000	0.1818 = D
16	14	0.7273	0.33	0.6306	0.0967
17	15	0.7727	0.67	0.7465	0.0262
18	15	0.8182	0.67	0.7465	0.0717
19	16	0.8636	1.00	0.8413	0.0223
20	16	0.9091	1.00	0.8413	0.0678
21	18	0.9545	1.67	0.9518	0.0022
22	19	1.0006	2.00	0.9772	0.0228

Test Result: D less than 0.28995; do not reject the null hypothesis.

Distribution Seven

Distribution Seven is the distribution of times to unload a 40K K-loader at an L-100 aircraft. Below is a stem and leaf display of the data, a set of test hypotheses, and the results of a Kolmogorov - Smirnov goodness of fit test. Because of the small sample size and chi-square's requirement that all cells counts be greater than or equal to five, the K-S test is used.

TABLE XVI

Distribution Seven Data
(In Minutes)

+1	0 0 1 1 2 3 3 4 4 4 5 5 5 5 6 6 7 8 8
+2	0 1 3

Sample size equals 22.
Sample mean equals 15.0455 minutes.
Sample standard deviation equals 3.4569 minutes.
Sample low value equals 10 minutes.
Sample high value equals 23 minutes.

Null Hypothesis: The sample was drawn from a population of values normally distributed with a mean of 15 minutes and a standard deviation of 3 minutes.

Alternate Hypothesis: The sample data was not drawn from a population of values normally distributed with a mean of 15 minutes and a standard deviation of 3 minutes.

Test: Kolmogorov - Smirnov goodness of fit at the 95% confidence level.

Rejection Region: Reject the null hypothesis if the maximum absolute difference between the empiric cumulative distribution function and the hypothesized cumulative distribution function, know as D, is greater than 0.3995 (36:251).

TABLE XVII

Distribution Seven Calculated D

n	x	S(x)	Z	F(x)	|F(x) - S(x)|
1	10	0.0454	-1.67	0.0482	0.0028
2	10	0.0909	-1.67	0.0482	0.0427
3	11	0.1364	-1.33	0.0912	0.0452
4	11	0.1818	-1.33	0.0912	0.0906
5	12	0.2272	-1.00	0.1587	0.0686
6	13	0.2727	-0.67	0.2535	0.0192
7	13	0.3182	-0.67	0.2535	0.0647
8	14	0.3636	-0.33	0.3694	0.0058
9	14	0.4091	-0.33	0.3694	0.0397
10	14	0.4545	-0.33	0.3694	0.0851
11	15	0.5000	0.00	0.5000	0.0000
12	15	0.5454	0.00	0.5000	0.0454
13	15	0.5909	0.00	0.5000	0.0909
14	15	0.6364	0.00	0.5000	0.1364 = D
15	16	0.6818	0.33	0.6306	0.0512
16	16	0.7273	0.33	0.6306	0.0967
17	17	0.7727	0.67	0.7465	0.0262
18	18	0.8182	1.00	0.8413	0.0231
19	18	0.8636	1.33	0.8413	0.0223
20	20	0.9091	1.67	0.9518	0.0427
21	21	0.9545	2.00	0.9772	0.0227
22	23	1.0000	2.67	0.9962	0.0038

Test Result: D less than 0.28995; do not reject the null hypothesis.

Distribution Eight

Distribution Eight is the distribution of times to load a 40K K-loader at an L-188 aircraft. Below is a stem and leaf display of the data, a set of test hypotheses, and the results of a Kolmogorov - Smirnov goodness of fit test. Because of the small sample size and chi-square's requirement that all cells counts be greater than or equal to five, the K-S test is used.

TABLE XVIII

Distribution Eight Data
(In Minutes)

+1	1 1 2 3 3 4 5 5 5 5 5
+1	6 6 6 7 7 7 7 7 7 7 8 8 8 8 8 9 9 9 9
+2	0 0 1 1 1 2 3 3 4 6 7

Sample size equals 41.
Sample mean equals 17.8049 minutes.
Sample standard deviation equals 3.7028 minutes.
Sample low value equals 2 minutes.
Sample high value equals 24 minutes.

Null Hypothesis: The sample was drawn from a population of values normally distributed with a mean of 18 minutes and a standard deviation of 4 minutes.

Alternate Hypothesis: The sample data was not drawn from a population of values normally distributed with a mean of 18 minutes and a standard deviation of 4 minutes.

Test: Kolmogorov - Smirnov goodness of fit at the 95% confidence level.

Rejection Region: Reject the null hypothesis if the maximum absolute difference between the empiric cumulative distribution function and the hypothesized cumulative distribution function, know as D, is greater than 0.21240 (36:251).

TABLE XIX

Distribution Eight Calculated D

n	x	S(x)	Z	F(x)	|F(x) - S(x)|
1	11	0.0244	-1.75	0.0401	0.0157
2	11	0.0488	-1.75	0.0401	0.0087
3	13	0.0732	-1.25	0.1056	0.0324
4	13	0.0732	-1.25	0.1056	0.0080
5	13	0.1220	-1.25	0.1056	0.0164
6	14	0.1463	-1.00	0.1587	0.0124
7	15	0.1707	-0.75	0.2266	0.0553
8	15	0.1951	-0.75	0.2266	0.0309
9	15	0.2195	-0.75	0.2266	0.0071
10	15	0.2439	-0.75	0.2266	0.0173
11	15	0.2683	-0.75	0.2266	0.0417
12	16	0.2927	-0.50	0.3085	0.0158
13	16	0.3171	-0.50	0.3085	0.0086
14	16	0.3415	-0.50	0.3085	0.0330
15	17	0.3658	-0.25	0.4013	0.0355
16	17	0.3902	-0.25	0.4013	0.0111
17	17	0.4146	-0.25	0.4013	0.0133
18	17	0.4390	-0.25	0.4013	0.0377
19	17	0.4634	-0.25	0.4013	0.0621
20	17	0.4878	-0.25	0.4013	0.0865
21	17	0.5122	-0.25	0.4013	0.1109
22	18	0.5366	0.00	0.5000	0.0366
23	18	0.5610	0.00	0.5000	0.0610
24	18	0.5854	0.00	0.5000	0.0854
25	18	0.6098	0.00	0.5000	0.1098
26	18	0.6341	0.00	0.5000	0.1341
27	19	0.6585	0.25	0.5948	0.0637
28	19	0.6829	0.25	0.5948	0.0881
29	19	0.7073	0.25	0.5948	0.1125
30	19	0.7317	0.25	0.5948	<u>0.1369</u> = D
31	20	0.7561	0.50	0.6915	0.0646
32	20	0.7805	0.50	0.6915	0.0890
33	21	0.8049	0.75	0.7734	0.0315
34	21	0.8293	0.75	0.7734	0.0559
35	21	0.8537	0.75	0.7735	0.0803
36	22	0.8780	1.00	0.8413	0.0367
37	23	0.9024	1.25	0.8944	0.0080
38	23	0.9268	1.25	0.8944	0.0324
39	24	0.9512	1.50	0.9332	0.0180
40	26	0.9756	2.00	0.9772	0.0016
41	27	1.0000	2.25	0.9878	0.0122

Test Result: D less than 0.2140; do not reject the null hypothesis.

Distribution Nine

Distribution Nine is the distribution of times to unload a 40K K-loader at an L-188 aircraft. Below is a stem and leaf display of the data, a set of test hypotheses, and the results of a Kolmogorov - Smirnov goodness of fit test. Because of the small sample size and chi-square's requirement that all cells counts be greater than or equal to five, the K-S test is used.

TABLE XX

Distribution Nine Data
(In Minutes)

+1	2 3 5 5 5 6 6 7 7 7 8 8 8 8 9 9 9
+2	0 0 0 0 0 0 1 1 1 1 1 2 2 3 3 3 4 5 5 7 8 8 9
+3	0

Sample size equals 41.
Sample mean equals 20.3902 minutes.
Sample standard deviation equals 4.2537 minutes.
Sample low value equals 12 minutes.
Sample high value equals 30 minutes.

Null Hypothesis: The sample was drawn from a population of values normally distributed with a mean of 20 minutes and a standard deviation of 4 minutes.

Alternate Hypothesis: The sample data was not drawn from a population of values normally distributed with a mean of 20 minutes and a standard deviation of 4 minutes.

Test: Kolmogorov - Smirnov goodness of fit at the 95% confidence level.

Rejection Region: Reject the null hypothesis if the maximum absolute difference between the empiric cumulative distribution function and the hypothesized cumulative distribution function, know as D, is greater than 0.21240 (36:251).

TABLE XXI

Distribution Nine Calculated D

n	x	S(x)	Z	F(x)	|F(x) - S(x)|
1	12	0.0244	-2.00	0.0228	0.0016
2	13	0.0488	-1.75	0.0401	0.0087
3	15	0.0732	-1.25	0.1056	0.0324
4	15	0.0732	-1.25	0.1056	0.0080
5	15	0.1220	-1.25	0.1056	0.0164
6	16	0.1463	-1.00	0.1587	0.0124
7	16	0.1707	-1.00	0.1587	0.0120
8	17	0.1951	-0.75	0.2266	0.0315
9	17	0.2195	-0.75	0.2266	0.0071
10	17	0.2439	-0.75	0.2266	0.0173
11	18	0.2683	-0.50	0.3085	0.0402
12	18	0.2927	-0.50	0.3085	0.0158
13	18	0.3171	-0.50	0.3085	0.0086
14	18	0.3415	-0.50	0.3085	0.0330
15	19	0.3658	-0.25	0.4013	0.0355
16	19	0.3902	-0.25	0.4013	0.0111
17	19	0.4146	-0.25	0.4013	0.0133
18	20	0.4390	0.00	0.5000	0.0610
19	20	0.4634	0.00	0.5000	0.0366
20	20	0.4878	0.00	0.5000	0.0122
21	20	0.5122	0.00	0.5000	0.0122
22	20	0.5366	0.00	0.5000	0.0366
23	20	0.5610	0.00	0.5000	0.0610
24	21	0.5854	0.25	0.5948	0.0094
25	21	0.6098	0.25	0.5948	0.0150
26	21	0.6341	0.25	0.5948	0.0393
27	21	0.6585	0.25	0.5948	0.0637
28	21	0.6829	0.25	0.5948	0.0881 = D
29	22	0.7073	0.50	0.6915	0.0158
30	22	0.7317	0.50	0.6915	0.0402
31	23	0.7561	0.75	0.7734	0.0173
32	23	0.7805	0.75	0.7734	0.0071
33	23	0.8049	0.75	0.7734	0.0315
34	24	0.8293	1.00	0.8413	0.0120
35	25	0.8537	1.25	0.8944	0.0407
36	25	0.8780	1.25	0.8944	0.0164
37	27	0.9024	1.75	0.9599	0.0575
38	28	0.9268	2.00	0.9772	0.0504
39	28	0.9512	2.00	0.9772	0.0260
40	29	0.9756	2.25	0.9878	0.0122
41	30	1.0000	2.50	0.9938	0.0062

Test Result: D less than 0.21240; do not reject the null hypothesis.

Distribution Ten

Distribution Ten is the distribution of the time to prepare an aircraft for take-off. Below is a stem and leaf display of the data, a set of test hypotheses, and the results of a chi-square goodness of fit test.

TABLE XXII

Distribution Ten Data
(In Minutes)

+0	5 5 7 8 8 8 9 9
+1	0 0 0 1 1 2 2 2 3 4 4 4 5 5 5 6 6 6 6 7 7 7 8 8 9 9
+2	1 1 2

Sample size equals 37.
Sample mean equals 13.5135 minutes.
Sample standard deviation equals 4.5008 minutes.
Sample low value equals 5 minutes.
Sample high value equals 22 minutes.

Null Hypothesis: The sample was drawn from a population of values uniformly distributed with a low of 5 minutes and a high of 22 minutes.

Alternate Hypothesis: The sample data was not drawn from a population of values uniformly distributed with a low of 5 minutes and a high of 22 minutes.

Test: Chi-square goodness of fit with two degrees of freedom and a 95% confidence level.

Rejection Region: Reject the null hypothesis if the calculated chi-square is greater than 5.99147 (26:899).

TABLE XXIII

Distribution Ten Calculated Chi-square

Range In Minutes	Expected Count (E)	Observed Count (O)	$(E-O)^2/E$
5.0 - 8.5	7.62	6.00	0.019
8.5 - 11.5	6.53	7.00	0.034
11.5 - 14.5	6.53	7.00	0.034
14.5 - 17.5	6.53	10.00	1.845
17.5 - 22.0	9.79	7.00	0.797
			3.053

Test Result: Calculated chi-square less than 5.99147; do not reject the null hypothesis.

Appendix B: Model Diagrams

The following diagrams present a schematic illustration of the sequenece of major activities of the SLAM II simulation models developed in this thesis. The CREATE, ASSIIGN, PARK, QUEUE, and TERMINATE boxes represent the major nodes of the models. The UNLOAD, LOAD, WAIT, and TAKEOFF boxes represent the major activities of the models. All other boxes are connectors. In the models most activities are preceeded by AWAIT nodes and followed by FREE nodes. These nodes collect and release resources as required. These nodes are not shown in the diagrams in this appendix.

A single 40K mission refers to a mission with only enough cargo to fill up at most one 40K K-loader. A double 40K mission refers to a mission with enough cargo to fill up at most two 40K K-loaders. ATTRIB'S stands for attributes, GND stands for ground, and TERM stands for entity termination.

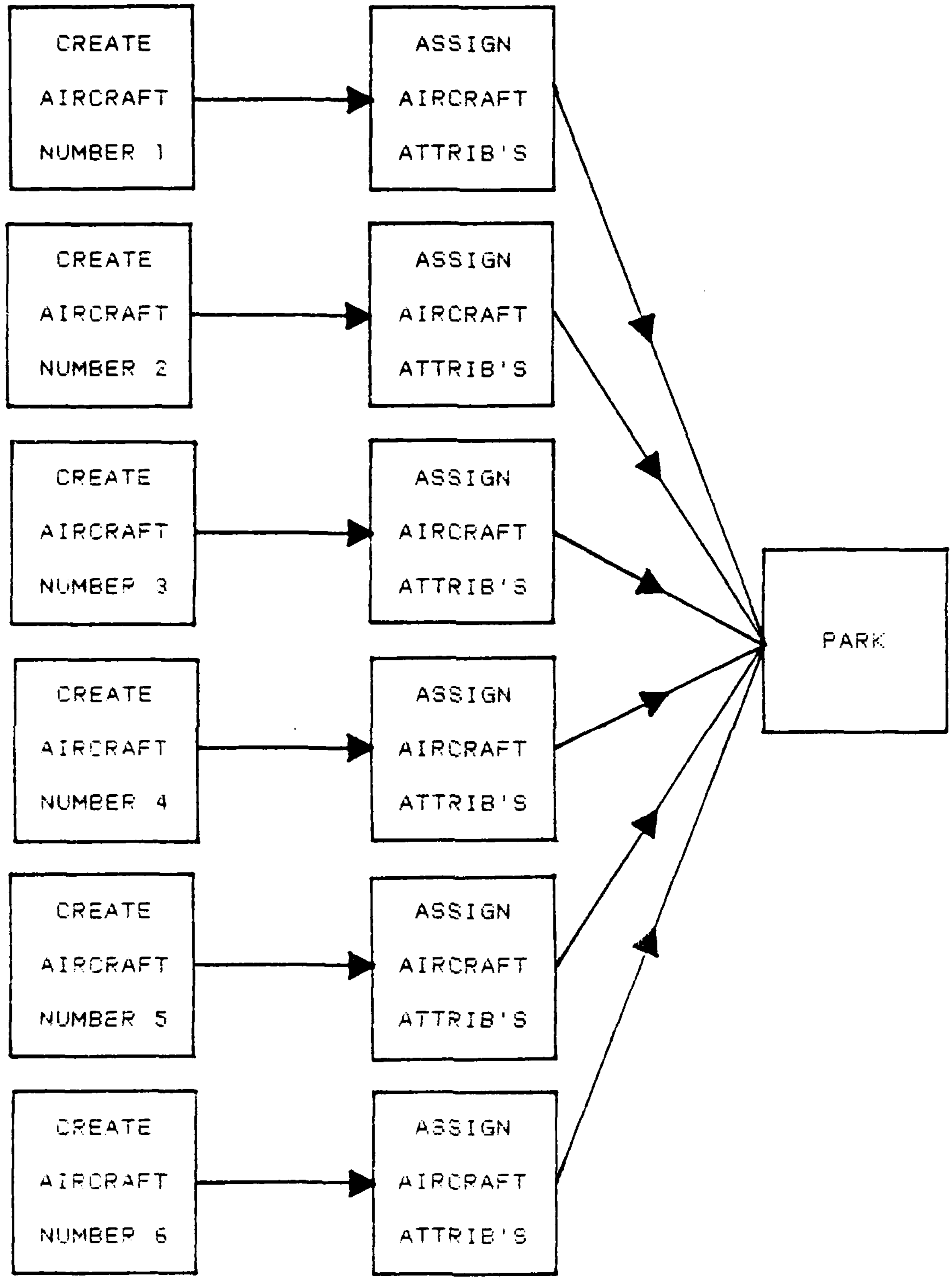


Figure 4. Aircraft Creation Model 1

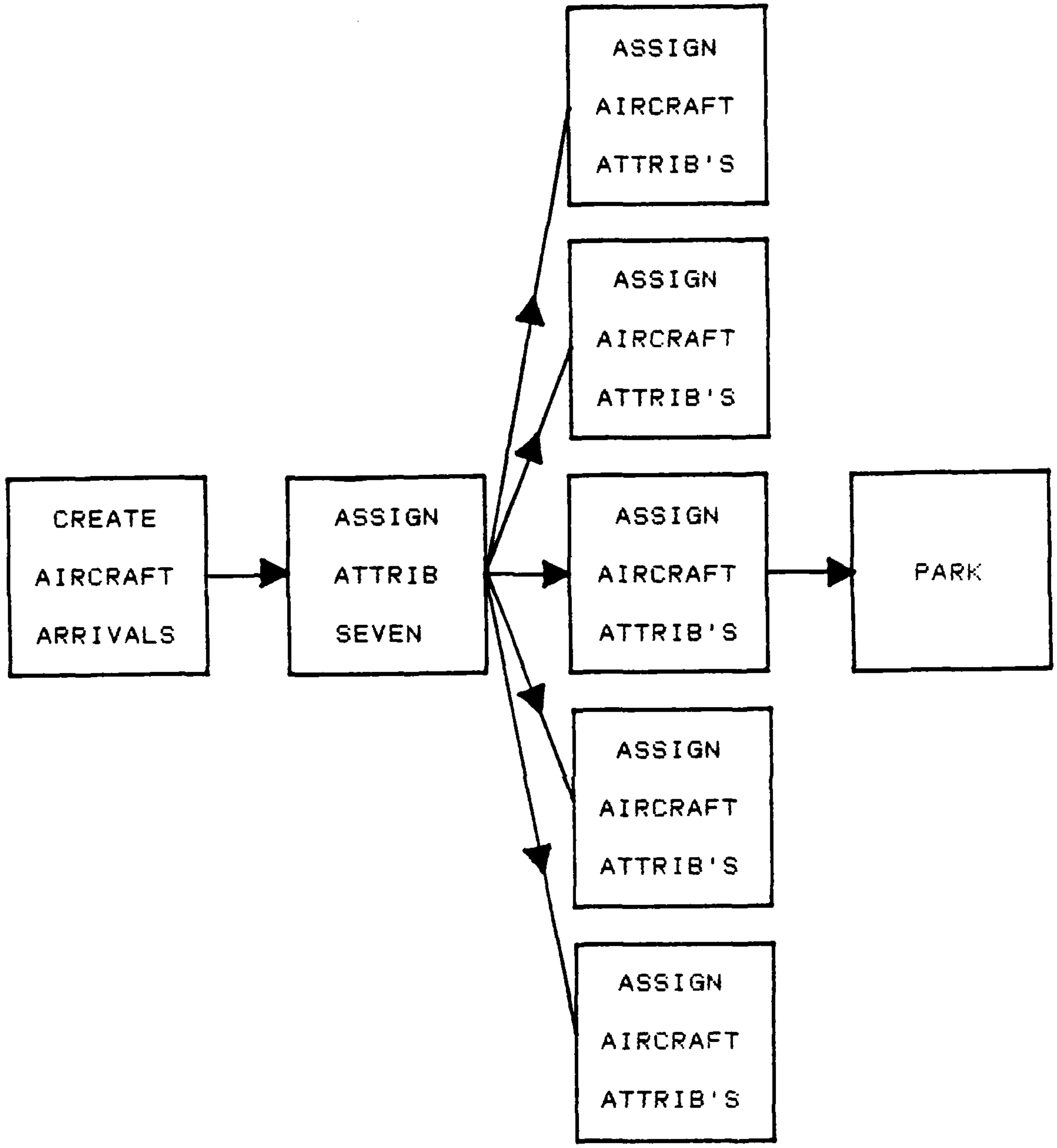


FIGURE 5. Aircraft Creation Model 2

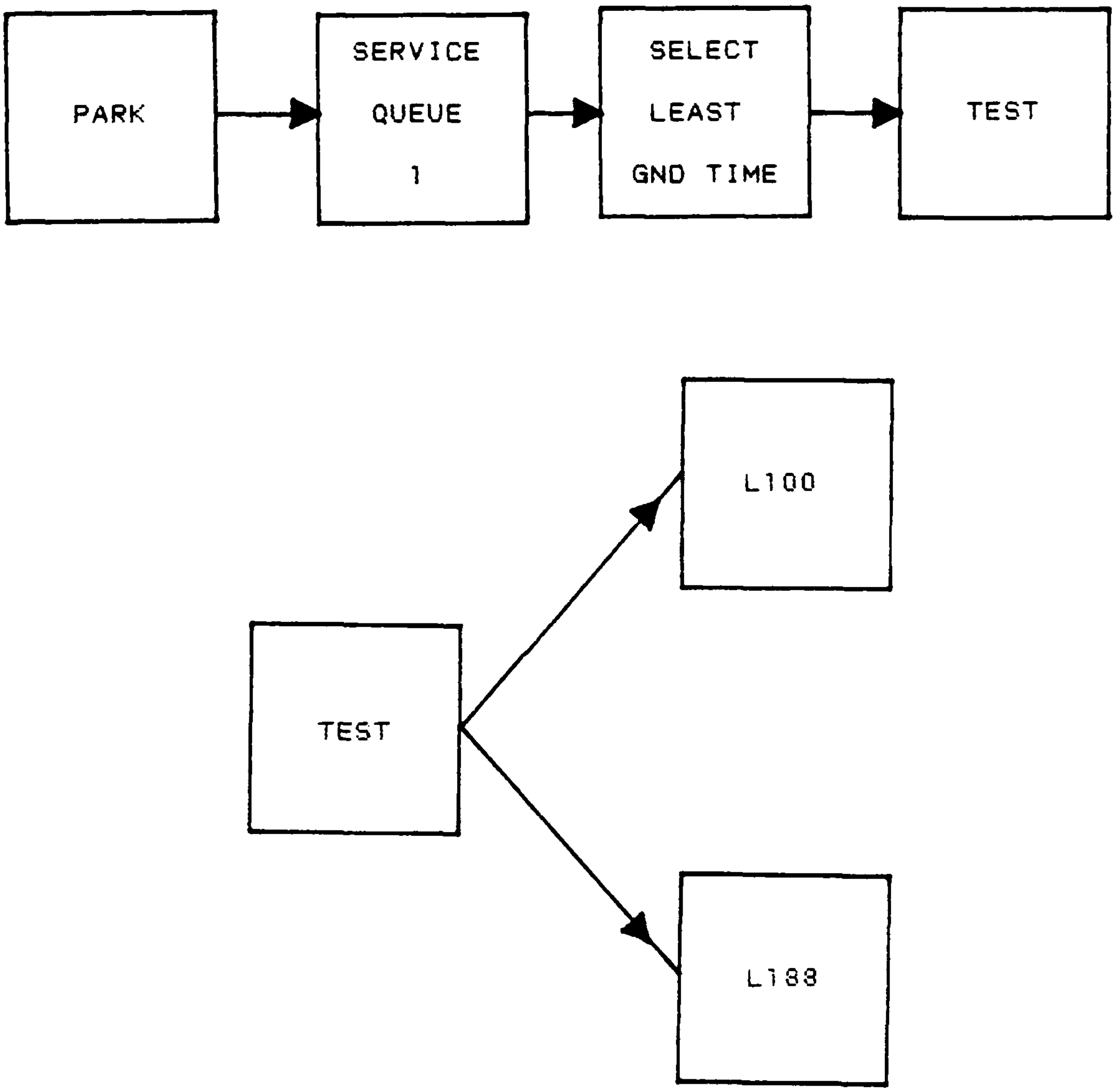


Figure 6. Aircraft Parking, Queueing, and Selecting

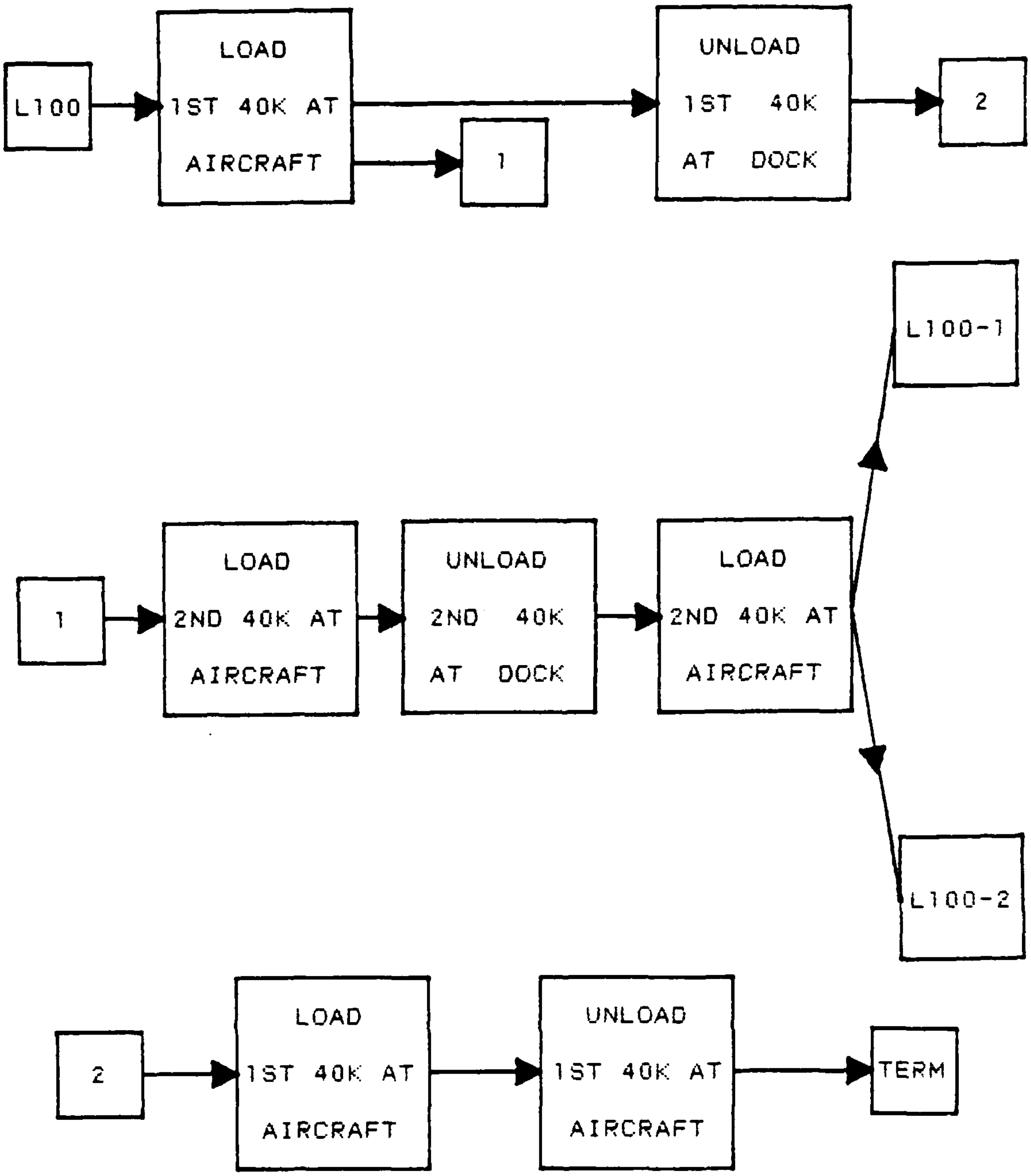


Figure 7. L-100 Common Activities

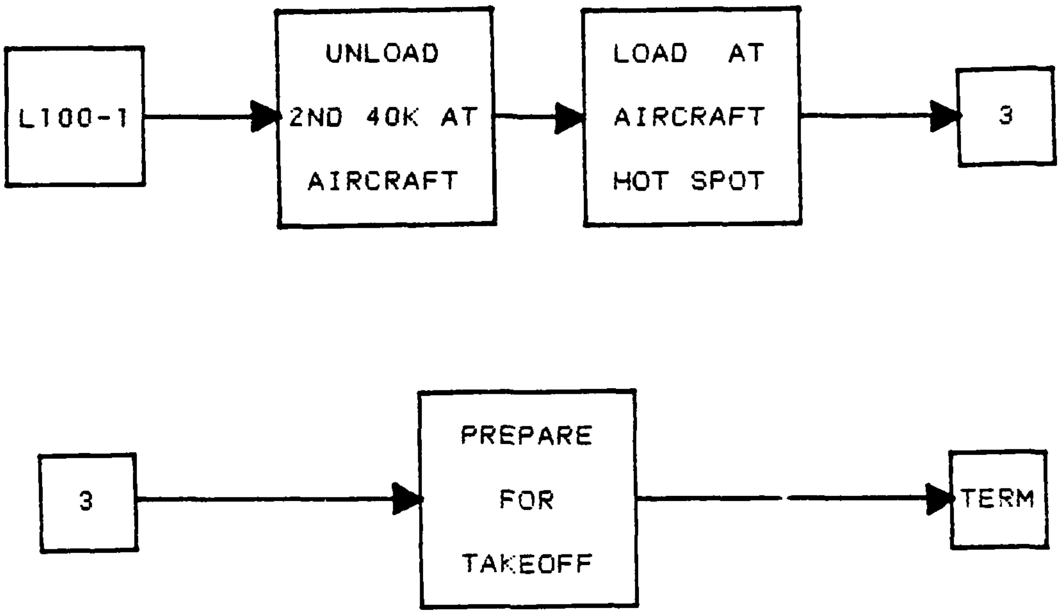


Figure 8. L-100 Double 40K, Hot Spot Mission

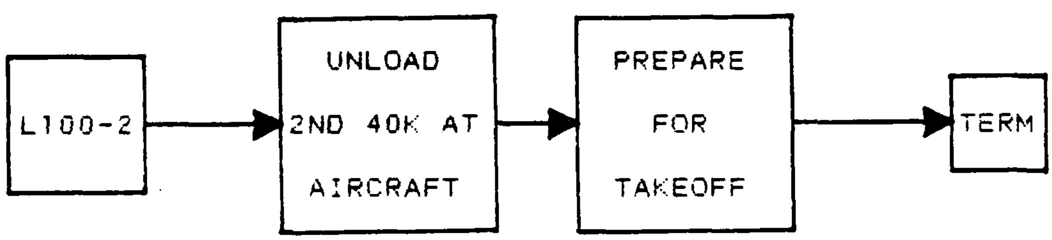


Figure 9. L-100 Double 40K Mission

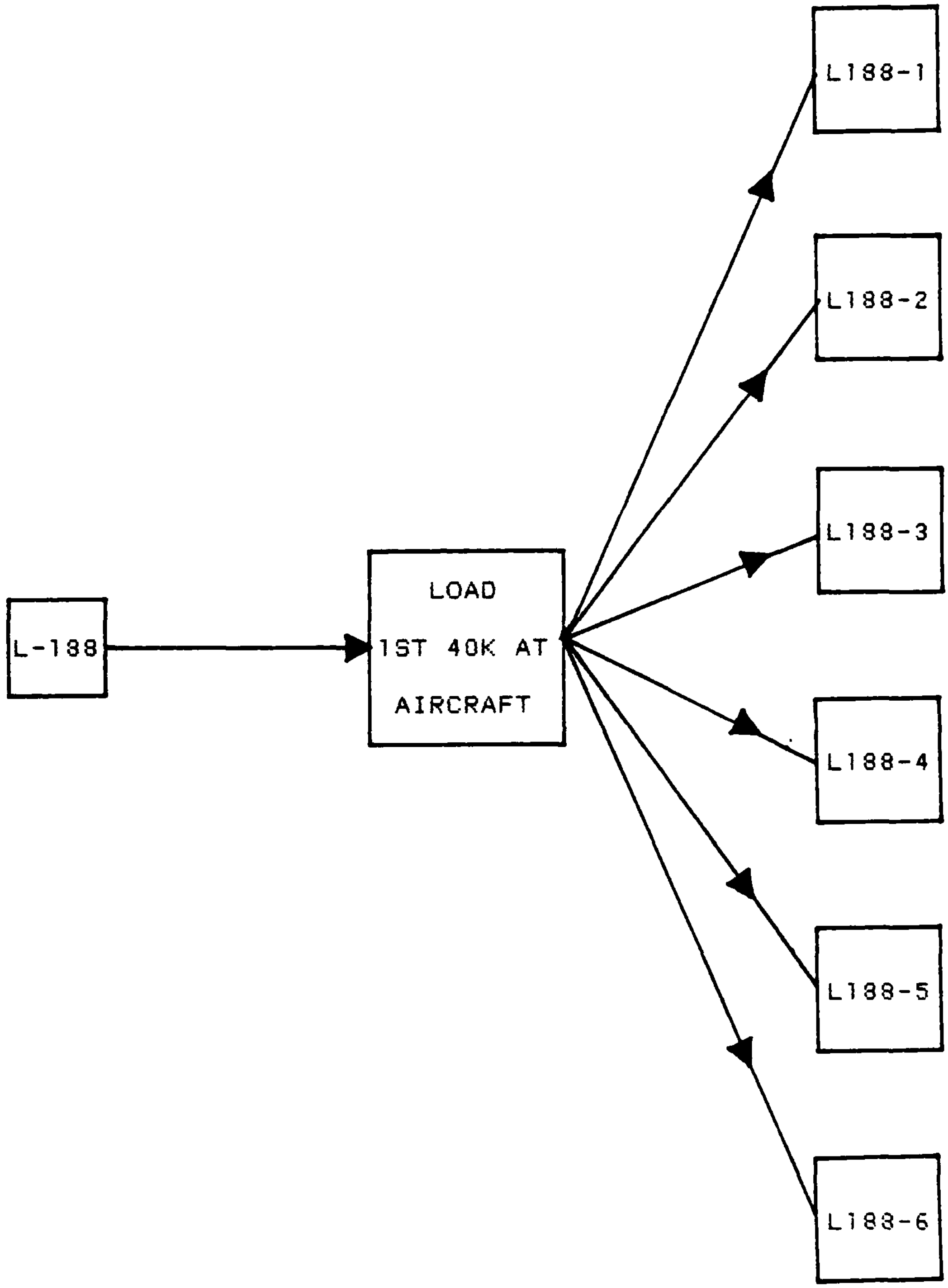


Figure 10. L-188 Common Activities

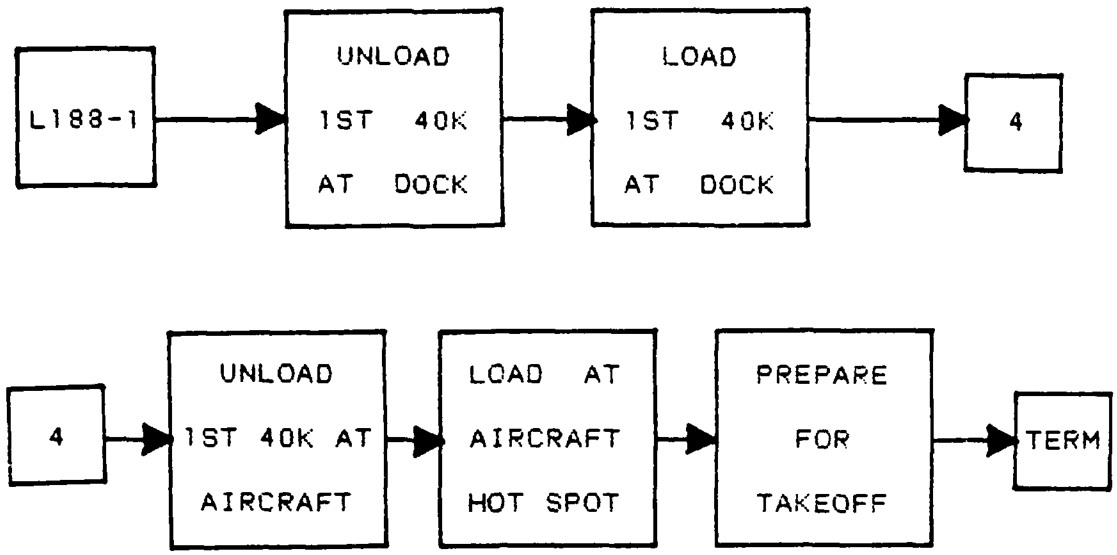


Figure 11. L-188 Single 40K, Hot Spot Mission

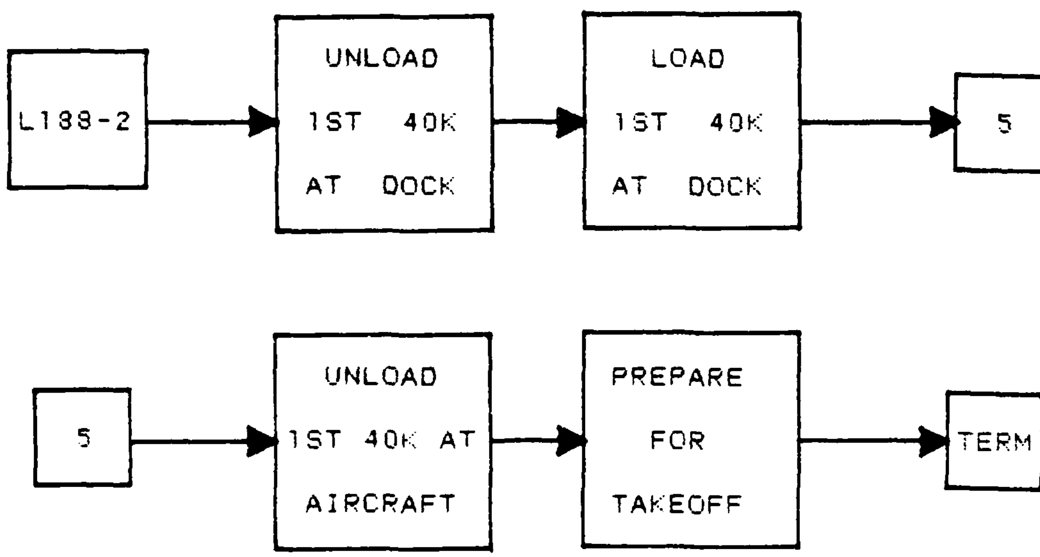


Figure 12. L-188 Single 40k Mission

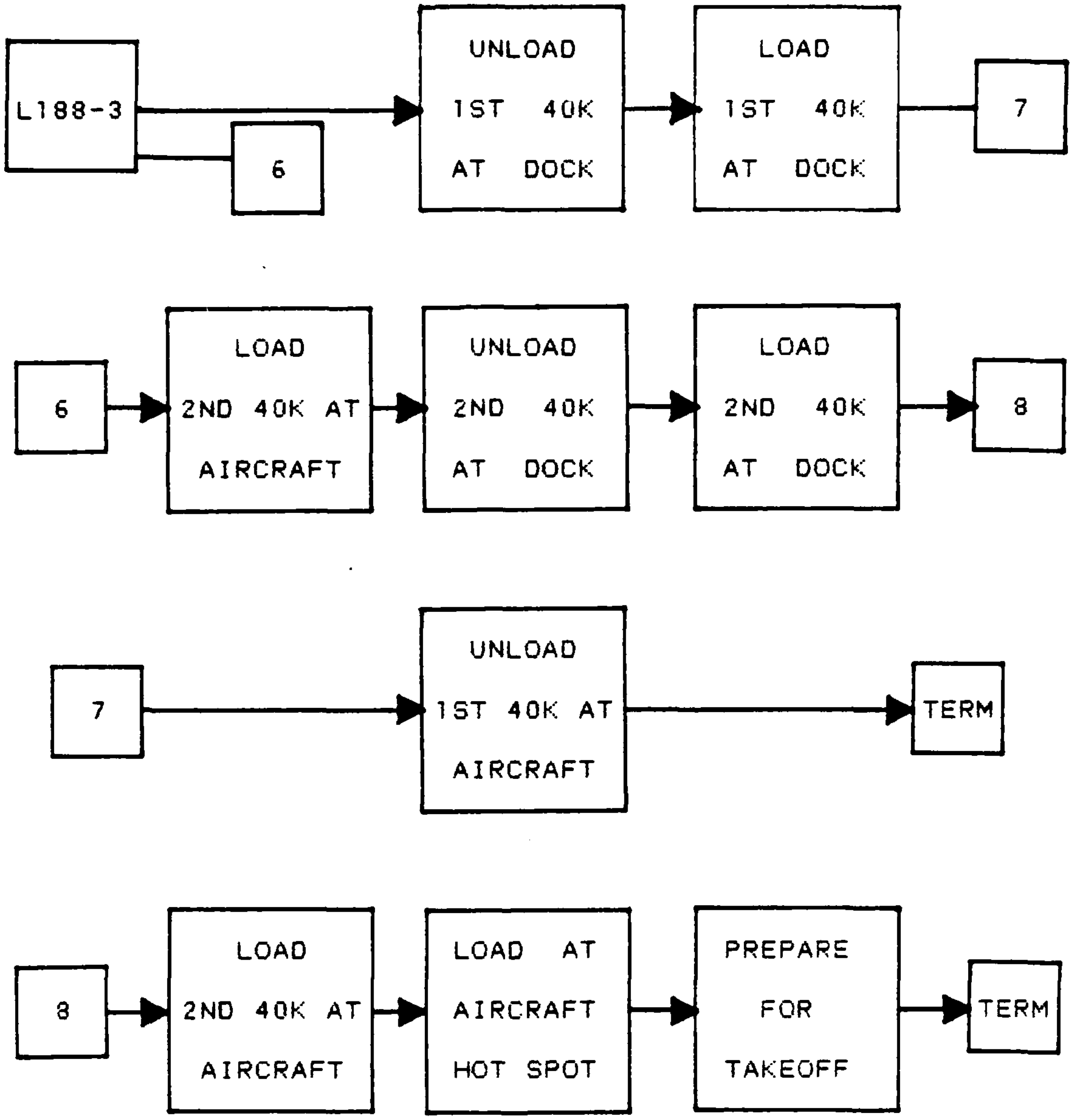


FIGURE 13. L-188 Double 40K, Hot Spot Mission

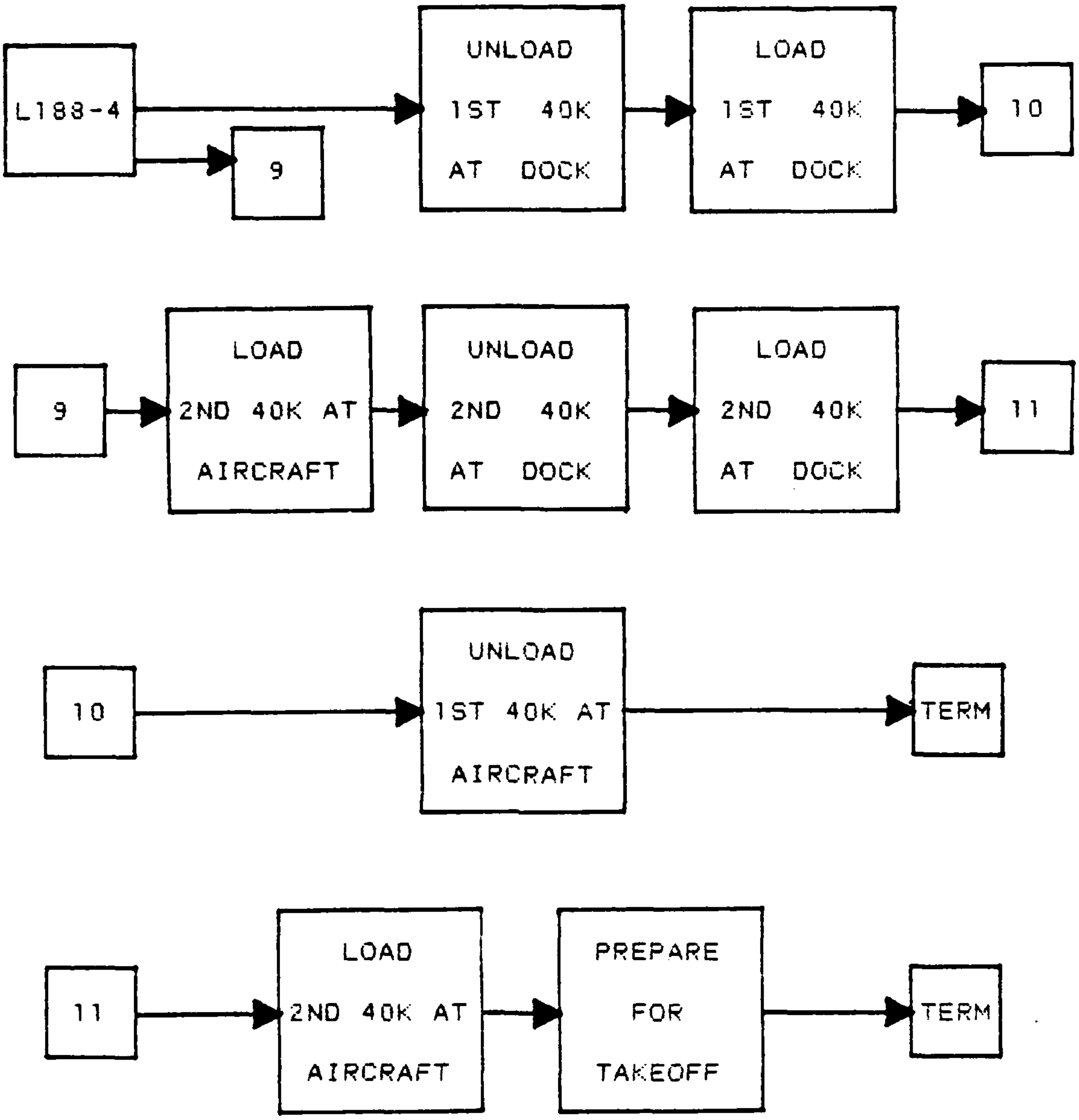


FIGURE 14. L-188 Double 40K Mission

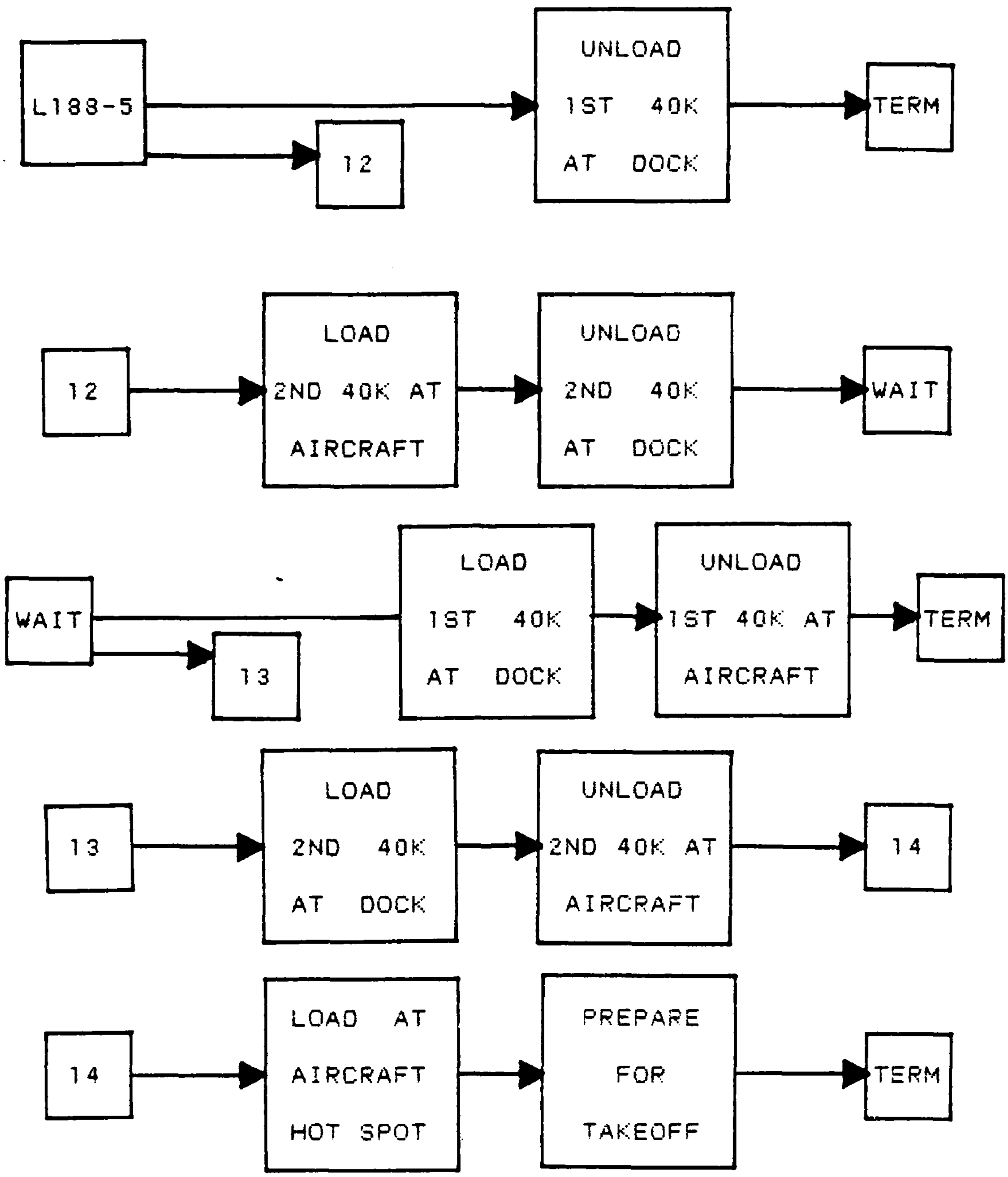


Figure 15. L-188 Double 40K, Terminating, Hot Spot Mission

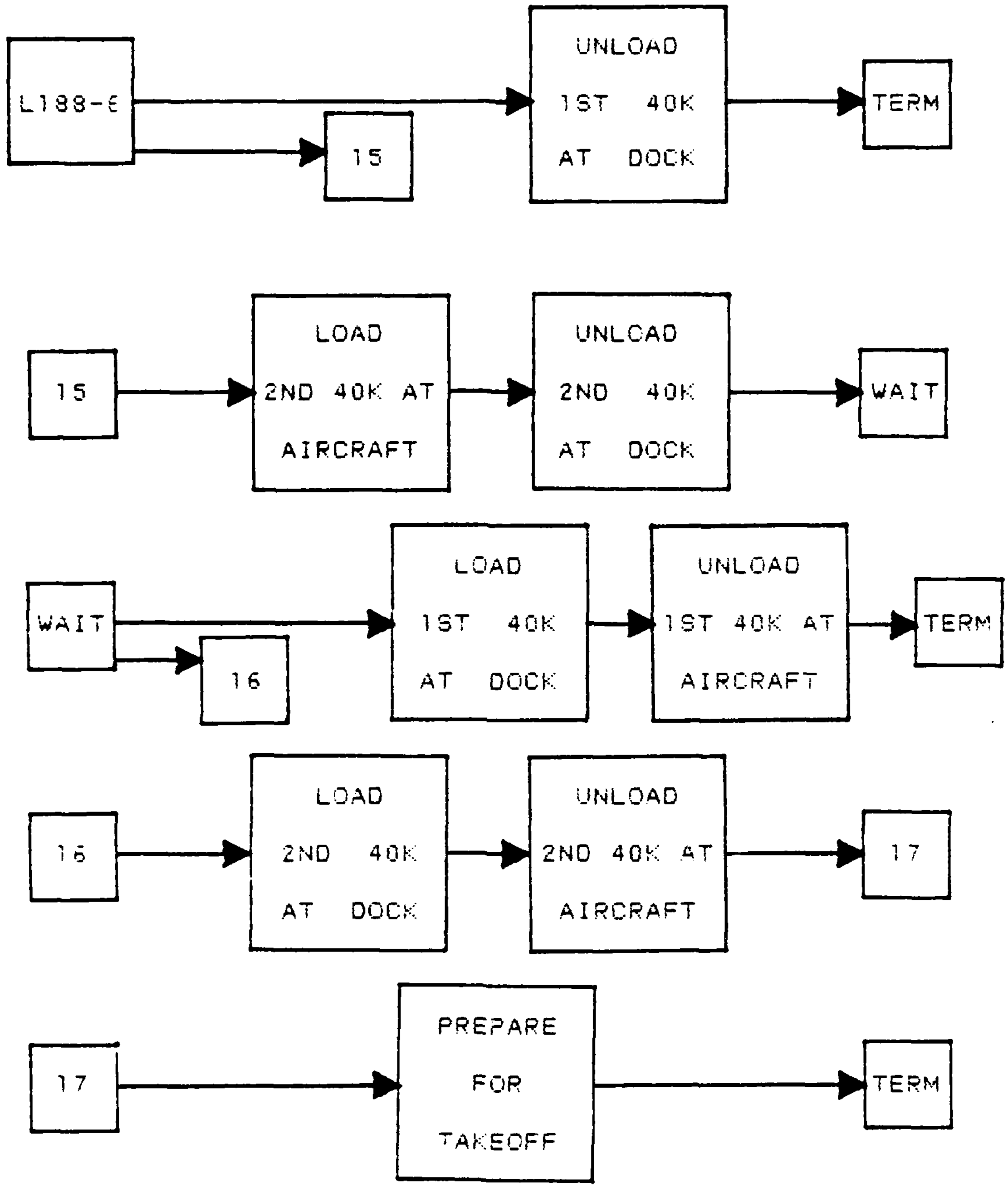


Figure 16. L-188 Double 40K, Terminating Mission

Appendix C: Model Code

The following code is an aggregation of the two SLAM II simulation models developed for this thesis. All comments on a line that appear after an ";" are not exxecuted. If a line of code is followed by an ";1" it is used only in Model 1; if it is followed by a ";2" it is used only in Model 2. All other statements are used in both models.

```
GEN, CAPT FREDETTE, MODEL
#,D/M/Y,1,YES,YES,YES,YES,YES/F,72;
LIMITS,99,6,25;1
LIMITS,99,7,25;2
PRIORITY/99,LVF(6);
INITIALIZE,0,30240,YES/1,YES,YES;
MONTR,CLEAR,1440;
MONTR,SUMRY,2880,1440;
NETWORK;
;
;The following statements establish the resource base.
;
        RESOURCE/WORK(1),2,19,63,86;
        RESOURCE/PARK(5),1;
        RESOURCE/AIRC(1),3,10,11,15,18,20,28,34,38,
        39,43,44,50,51,55,59,69,75,76,82,92,98;
        RESOURCE/HTPT(1),16,29,45,77;
        RESOURCE/DOCK(1),7,12,25,31,35,
        40,47,52,56,60,65,72,79,83,88,95;
        RESOURCE/KL40(50),4,21,64,87;
        RESOURCE/FLPU(50),17,30,46,78;
        RESOURCE/TUGS(50),24,68,91;
        RESOURCE/MP70(100),5,8,13,22,26,32,36,41,
        48,53,57,61,66,70,73,80,84,89,93,96;
        RESOURCE/MP50(400),6,9,14,23,27,33,37,42,
        49,54,58,62,67,71,74,81,85,90,94,97;
;
;The following statements create aircraft arrivals for Model
2 and they direct them to the proper node for assignment of
attributes.
;
        CREATE,EXPON(240,1),19,1,150,1;2
        ASSIGN,ATRIB(7)=UNFRM(0,90,2);2
        ACTIVITY/91,0,ATRIB(7).LE.30,CRT1;2
```

```
        ACTIVITY/92,0,ATRIB(7).GT.30.AND.ATRIB(7).LE.45,CRT3;
2
        ACTIVITY/93,0,ATRIB(7).GT.45.AND.ATRIB(7).LE.60,CRT4;
2
        ACTIVITY/94,0,ATRIB(7).GT.60.AND.ATRIB(7).LE.75,CRT5;
2
        ACTIVITY/95,0,ATRIB(7).GT.75,CRT6;2
;
;The following statements create aircraft arrivals for Model
1, assign aircraft attributes for both models, and directs
them to the PARK node.
;
        CREATE,RNORM(1440,29,1),19,1,25,1;1
CRT1    ASSIGN,ATRIB(2)=1,
                ATRIB(3)=16,
                ATRIB(4)=UNFRM(0,100,1),
                ATRIB(5)=1,
                ATRIB(6)=120;
        ACTIVITY/1,0,1,PARK;
;
        CREATE,RNORM(1440,29,2),739,1,25,1;1
        ASSIGN,ATRIB(2)=1,
                ATRIB(3)=16,
                ATRIB(4)=UNFRM(0,100,2),
                ATRIB(5)=1,
                ATRIB(6)=120;1
        ACTIVITY/2,0,1,PARK;2
;
        CREATE,RNORM(1440,29,3),824,1,25,1;1
CRT3    ASSIGN,ATRIB(2)=2,
                ATRIB(3)=8,
                ATRIB(4)=UNFRM(0,100,3),
                ATRIB(5)=1,
                ATRIB(6)=90;
        ACTIVITY/3,0,1,PARK;
;
        CREATE,RNORM(1440,29,4),859,1,25,1;1
CRT4    ASSIGN,ATRIB(2)=2,
                ATRIB(3)=18,
                ATRIB(4)=UNFRM(0,100,4),
                ATRIB(5)=1,
                ATRIB(6)=90;
        ACTIVITY/4,0,1,PARK;
;
        CREATE,RNORM(1440,29,5),1044,1,25,1;1
CRT5    ASSIGN,ATRIB(2)=2,
                ATRIB(3)=18,
                ATRIB(4)=UNFRM(0,100,5),
                ATRIB(5)=2,
                ATRIB(6)=760;
        ACTIVITY/5,0,1,PARK;
;
```

```
CRT6    CREATE,RNORM(1440,29,6),1149,1,25,1;1
        ASSIGN,ATRIB(2)=2,
               ATRIB(3)=18,
               ATRIB(4)=UNFRM(0,100,6),
               ATRIB(5)=2,
               ATRIB(6)=705;
        ACTIVITY/6,0,1,PARK;
;
;The following statements park the aircraft, place the
aircraft into a queue, select the aircraft from the queue
based on the remaining ground time, and route the aircraft
to differnt nodes based on aircraft type.
;
PARK    AWAIT(1),PARK/1;
        ACTIVITY/7,UNFRM(2,24,2),1,QU01;
QU01    QUEUE(99),0,;
        ACTIVITY/8,0,1,GN01;
GN01    GOON,1;
        ACTIVITY/9,0,ATRIB(2).EQ.1,GN02;
        ACTIVITY/10,0,ATRIB(2).EQ.2,GN03;
        TERMINATE;
;
;The following statements up to the second TERMINATE
statement service all L-100 aircraft.  The first block of
statements loads the first K-loader at the aircraft.
;
GN02    AWAIT(2),WORK/1;
        AWAIT(3),AIRC/1;
        AWAIT(4),KL40/2;
        AWAIT(5),MP70/1;
        AWAIT(6),MP50/5;
        ACTIVITY/11,RNORM(13,3,9),1;
        FREE,AIRC/1,2;
;
;The following statements split the aircraft entity so that
dockside and aircraft operations can concurrently exist.
;
        ACTIVITY/12,,,GN1A;
        ACTIVITY/13,,;
;
;The following statements unload and load the first K-loader
at the dock.
;
        AWAIT(7),DOCK/1;
        AWAIT(8),MP70/1;
        AWAIT(9),MP50/3;
        ACTIVITY/14,UNFRM(4,15,1),1;
        GOON;
        ACTIVITY/15,UNFRM(4,37,2),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE.MP50/3;
```

```
;
;The following statements unload the first K-loader at the
aircraft.
;
        AWAIT(10),AIRC/1;
        ACTIVITY/16,RNORM(15,3,3),1;
        FREE,AIRC/1;
        FREE,KL40/1;
        FREE,MP50/1;
        TERMINATE;
;
;The following statements load the second K-loader at the
aircraft.
;
GN1A    AWAIT(11),AIRC/1;
        ACTIVITY/17,RNORM(13,3,4),1;
        FREE,AIRC/1;
;
;The following statements unload and load the second
K-loader at the dock.
;
        AWAIT(12),DOCK/1;
        AWAIT,MP70/1;
        AWAIT(14).MP50/3;
        ACTIVITY/18,UNFRM(4,15,5(,1;
        GOON;
        ACTIVITY/19,UNFRM(4,27,6),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/3,1;
;
;The following statements branch the aircraft entities to
one of two nodes.  Each node services a different L-100
mission.
;
        ACTIVITY/20,0,ATRIB(4).LE.11.G103;
        ACTIVITY/21,0,ATRIB(4).GT.11,G104;
        TERMINATE;
;
;The following statements unload the second K-loader at the
aircraft.
;
G103    AWAIT(15),AIRC/1;
        ACTIVITY/22,RNORM(15,3,7),1;
        FREE,KL40/1;
        FREE,MP50/1;
        FREE.PARK/1;
;
;The following statements load the aircraft at the hot spot.
;
        AWAIT(16),HTPT/1;
        AWAIT(17),FLPU/1;
```

```
        ACTIVITY/23,UNFRM(18,36,8),1;
        FREE,AIRC/1;
        FREE,HTPT/1;
        FREE,FLPU/1;
        FREE,MP70/1;
        FREE,MP50/3;
        FREE,WORK/1;
;
;The following statements prepare the aircraft for take-off
and terminate the entity.
;
        ACTIVITY/24,UNFRM(5,22,9),1;
        TERMINATE;
;
;The following statements unload the second K-loader at the
aircraft.
;
G104    AWAIT(18),AIRC/1;
        ACTIVITY/25,RNORM(15,3,8),1;
        FREE,AIRC/1;
        FREE,KL40/1;
        FREE,MP70/1;
        FREE,MP50/4;
        FREE,WORK/1;
;
;The following statements prepare the aircraft for take-off
and terminate the entity.
;
        ACTIVITY/26,UNFRM(5,22,9),1;
        FREE,PARK/1;
        TERMINATE;
;
;The following statements in the next two blocks of
statements service all L-188 aircraft.  The first block of
statements loads the first K-loader at the aircraft.
;
GN03    AWAIT(19),WORK/1;
        AWAIT(20),AIRC/1;
        AWAIT(21),KL40/2;
        AWAIT(22),MP70/1;
        AWAIT(23),MP50/5;
        AWAIT(24),TUGS/1;
        ACTIVITY/27,RNORM(18,4,1),1;
        FREE,AIRC/1,1;
;
;The following statements route the aircraft entities to one
of six nodes.  Each node services the aircraft based on the
aircraft's cargo mission.
;
        ACTIVITY/28,0,ATRIB(3).LE.10.AND.
                      ATRIB(5).EQ.1.AND.
                      ATRIB(4).LE.11,G201;
```

```
        ACTIVITY/29,0,ATRIB(3).LE.10.AND.
                      ATRIB(5).EQ.1.AND.
                      ATRIB(4).GT.11,G202;
        ACTIVITY/30,0,ATRIB(3).GT.10.AND.
                      ATRIB(5).EQ.1.AND.
                      ATRIB(4).LE.11,G203;
        ACTIVITY/31,0,ATRIB(3).GT.10.AND.
                      ATRIB(5).EQ.1.AND.
                      ATRIB(4).GT.11,G204;
        ACTIVITY/32,0,ATRIB(3).GT.10.AND.
                      ATRIB(5).EQ.2.AND.
                      ATRIB(4).LE.11,G205;
        ACTIVITY/33,0,ATRIB(3).GT.10.AND.
                      ATRIB(5).EQ.2.AND.
                      ATRIB(4).GT.11,G206;
        TERMINATE;
;
;The following statements unload and load the first K-loader
at the dock.
;
G201    AWAIT(25),DOCK/1;
        AWAIT(26),MP70/1;
        AWAIT(27),MP50/3;
        ACTIVITY/34,UNFRM(4,15,8),1;
        GOON;
        ACTIVYT/35,UNFRM(4,27,9),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/3;
;
;The following statements unload the first K-loader at the
aircraft.
;
        AWAIT(28),AIRC/1;
        ACTIVITY/36,RNORM(20,4,1),1;
        FREE,PARK/1;
        FREE,KL40/2;
        FREE,MP50/2;
        FREE,TUGS/1;
;
;The following statements load the aircraft at the hot spot.
;
        AWAIT(29),HTPT/1;
        AWAIT(30),FLPU/1;
        ACTIVITY/37,UNFRM(18,36,2),1;
        FREE,AIRC/1;
        FREE,HTPT/1;
        FREE,FLPU/1;
        FREE,MP70/1;
        FREE,MP50/3;
        FREE,WORK/1;
;
```

```
;The following statements prepare the aircraft for take-off
and terminate the aircraft entity.
;
        ACTIVITY/38,UNFRM(5,22,3);
        TERMINATE;
;
;The following statements unload and load the first K-loader
at the dock.
;
G202    AWAIT(31),DOCK/1;
        AWAIT(32),MP70/1;
        AWAIT(33),MP50/3;
        ACTIVITY/39,UNFRM(4,15,5),1;
        GOON;
        ACTIVYT/40,UNFRM(4,27,6),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/3;
;
;The following statements unload the first K-loader at the
aircraft.
;
        AWAIT(34),AIRC/1;
        ACTIVITY/41,RNORM(20,4,7),1;
        FREE,AIRC/1;
        FREE,KL40/2;
        FREE,MP70/1;
        FREE,MP50/5;
        FREE,TUGS/1;
        FREE,WORK/1;
;
;The following statements prepare the aircraft for take-off
and terminate the aircraft entity.
;
        ACTIVITY/42,UNFRM(5,22,8),1;
        TERMINATE;
;
;The following statements split the aircraft entity into two
in order to accommodate concurrent operations.
;
G203    GOON,2;
        ACTIVITY/43,,,GN2A;
        ACTIVITY/44,,;
;
;The following statements unload and load the first K-loader
at the dock.
;
        AWAIT(35),DOCK/1;
        AWAIT(36),MP70/1;
        AWAIT(37),MP50/3;
        ACTIVITY/45,UNFRM(4,15,1),1;
        GOON;
```

```
        ACTIVITY/46,UNFRM(4,27,2),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/3;
;
;The following statements unload the first K-loader at the
aircraft.
;
        AWAIT(38),AIRC/1;
        ACTIVITY/47,RNORM(20,4,3),1;
        FREE,AIRC/1;
        FREE,KL40/1;
        FREE,MP50/1;
        TERMINATE;
;
;The following statements load the second K-loader at the
aircraft.
;
GN2A    AWAIT(39),AIRC/1;
        ACTIVITY/48,RNORM(18,4,),1;
        FREE,AIRC/1;
;
;The following statements unload and load the second
K-loader at the dock.
;
        AWAIT(40),DOCK/1;
        AWAIT(41),MP70/1;
        AWAIT(42),MP50/3;
        ACTIVITY/49,UNFRM(4,15,5),1;
        GOON;
        ACTIVITY/50,UNFRM(4,27,6),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/3;
;
;The following statements unload the second K-loader at the
aircraft.
;
        AWAIT(43),AIRC/1;
        ACTIVITY/51,RNORM(20,4,7),1;
        FREE,AIRC/1;
        FREE,PARK/1;
        FREE,KL40/1;
        FREE,TUGS/1;
        FREE,MP50/2;
;
;The following statements load the aircraft at the hot spot.
;
        AWAIT(44),AIRC/1;
        AWAIT(45),HTPT/1;
        AWAIT(46),FLPU/1;
        ACTIVITY/52,UNFRM(18,36,8),1;
```

```
        FREE,AIRC/1;
        FREE,HTPT/1;
        FREE,FLPU/1;
        FREE,MP70/1;
        FREE,MP50/2;
        FREE,WORK/1;
;
;The following statements prepare the aircraft for take-off
and terminate the aircraft entity.
;
        ACTIVITY/53,UNFRM(5,22,9),1;
        TERMINATE;
;
;The following statements split the aircraft entity into two
in order to accommodate concurrent operations.
;
G204    GOON,2;
        ACTIVITY/54,,,GN2B;
        ACTIVITY/55,,;
;
;The following statements unload and load the first K-loader
at the dock.
;
        AWAIT(47),DOCK/1;
        AWAIT(48),MP70/1;
        AWAIT(49),MP50/3;
        ACTIVITY/56,UNFRM(4,15,2),1;
        GOON;
        ACTIVITY/57,UNFRM(4,27,3),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/3;
;
;The following statements unload the first K-loader at the
aircraft.
;
        AWAIT(50),AIRC/1;
        ACTIVITY/58,RNORM(20,4,4),1;
        FREE,AIRC/1;
        FREE,KL40/1;
        FREE,MP50/1;
        TERMINATE;
;
;The following statements load the second K-loader at the
aircraft.
;
GN2B    AWAIT(51),AIRC/1;
        ACTIVITY/59,RNORM(18,4,4),1;
        FREE,AIRC/1;
;
;The following statements unload and load the second
K-loader at the dock.
```

```
;
        AWAIT(52),DOCK/1;
        AWAIT(53),MP70/1;
        AWAIT(54),MP50/3;
        ACTIVITY/60,UNFRM(4,15,6),1;
        GOON;
        ACTIVITY/61,UNFRM(4,27,7),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/3;
;
;The following statements unload the second K-loader at the
aircraft.
;
        AWAIT(55),AIRC/1;
        ACTIVITY/62,RNORM(20,4,8),1;
        FREE,AIRC/1;
        FREE,KL40/1;
        FREE,TUGS/1;
        FREE,MP70/1;
        FREE,MP50/4;
        FREE,WORK/1;
;
;The following statements prepare the aircraft for take-off
and terminate the aircraft entity.
;
        ACTIVITY/63,UNFRM(5,22,9),1;
        FREE,PARK/1;
        TERMINATE;
;
;The following statements split the aircraft entity into two
in order to accommodate concurrent operations.
;
G205    GOON,2;
        ACTIVITY/64,,,GN2C;
        ACTIVITY/65,,;
;
;The following statements unload the first K-loader at the
dock.
;
        AWAIT(56),DOCK/1;
        AWAIT(57),MP70/1;
        AWAIT(58),MP50/3;
        ACTIVITY/66,UNFRM(4,15,2),1;
        FREE,KL40/1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/4;
        TERMINATE;
;
;The following statements load the second K-loader at the
aircraft.
```

```
;
GN2C    AWAIT(59),AIRC/1;
        ACTIVITY/67,RNORM(18,4,3),1;
        FREE,AIRC/1;
        FREE,MP70/1;
        FREE,MP50/3;
;
;The following staements unload the second K-loader at the
dock.
;
        AWAIT(60),DOCK/1;
        AWAIT(61),MP70/1;
        AWAIT(62),MP50/3;
        ACTIVITY/68,UNFRM(4,15,4),1;
        FREE,KL40/1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/4;
        FREE,TUGS/1;
        FREE,WORK/1;
;
;The following statements wait for the warehouse processing
of cargo to be accomplished before aircraft loading
operations can start.
;
        ACTIVITY/69,UNFRM(455,652,5),1;
        GOON;
;
;The following statements load the first K-loader at the
dock.
;
        AWAIT(63),WORK/1;
        AWAIT(64),KL40/2;
        AWAIT(65),DOCK/1;
        AWAIT(66),MP70/1;
        AWAIT(67),MP50/5;
        AWAIT(68),TUGS/1;
        ACTIVITY/70,UNFRM(4,27,6),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/3,2;
;
;The following statements split the aircraft entity into two
in order to accommodate concurrent operations.
;
        ACTIVITY/71,,,GN2D;
        ACTIVITY/72,,;
;
;The following statements unload the first K-loader at the
aircraft.
;
        AWAIT(69),AIRC/1;
```

```
        AWAIT(70),MP70/1;
        AWAIT(71),MP50/3;
        ACTIVITY/73,RNORM(20,4,7),1;
        FREE,AIRC/1;
        FREE,KL40/1;
        FREE,MP50/1;
        TERMINATE;
;
;The following statements load the second K-loader at the
dock.
;
GN2D    AWAIT(72),DOCK/1;
        AWAIT(73),MP70/1;
        AWAIT(74),MP50/3;
        ACTIVITY/74,UNFRM(4,27,8),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/3;
;
;The following statements unload the second K-loader at the
aircraft.
;
        AWAIT(75),AIRC/1;
        ACTIVITY/75,RNORM(20,4,9),1;
        FREE,AIRC/1;
        FREE,PARK/1;
        FREE,KL40/1;
        FREE,MP50/2;
        FREE,TUGS/1;
;
;The following statements load the aircraft at the hot spot.
;
        AWAIT(76),AIRC/1;
        AWAIT(77),HTPT/1;
        AWAIT(78),FLPU/1;
        ACTIVITY/76,UNFRM(18,36,1),1;
        FREE,AIRC/1;
        FREE,HTPT/1;
        FREE,FLPU/1;
        FREE,MP70/1;
        FREE,MP50/2;
        FREE,WORK/1;
;
;The following statements prepare the aircraft for take-off
and terminate the aircraft entity.
;
        ACTIVITY/77,UNFRM(5,22,2),1;
        TERMINATE;
;
;The following statements split the aircraft entity into two
in order to accommodate concurrent operations.
;
```

```
G206    GOON,2;
        ACTIVITY/78,,,GN2E;
        ACTIVITY/79,,;
;
;The following statements unload the first K-loader at the
dock.
;
        AWAIT(79),DOCK/1;
        AWAIT(80),MP70/1;
        AWAIT(81),MP50/3;
        ACTIVITY/80,UNFRM(4,15,3),1;
        FREE,KL40/1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/4;
        TERMINATE;
;
;The following statements load the second K-loader at the
aircraft.
;
GN2E    AWAIT(82),AIRC/1;
        ACTIVITY/81,RNORM(18,4,3),1;
        FREE,AIRC/1;
        FREE,MP70/1;
        FREE,MP50/3;
;
;The following statements unload the second K-loader at the
dock.
;
        AWAIT(83),DOCK/1;
        AWAIT(84),MP70/1;
        AWAIT(85),MP50/3;
        ACTIVITY/82,UNFRM(4,15,4),1;
        FREE,KL40/1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/4;
        FREE,TUGS/1;
        FREE,WORK/1;
;
;The following statements wait until cargo processing in the
warehouse is accomplished before starting aircraft loading
operations.
;
        ACTIVITY/83,UNFRM(455,652,5),1;
        GOON;
;
;The following statements load the first K-loader at the
dock.
;
        AWAIT(86),WORK/1;
        AWAIT(87),KL40/2;
```

```
        AWAIT(88),DOCK/1;
        AWAIT(89),MP70/1;
        AWAIT(90),MP50/5;
        AWAIT(91),TUGS/1;
        ACTIVITY/84,UNFRM(4,27,6),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/3,2;
;
;The following statements split the aircraft entity into two
in order to accommodate concurrent operations.
;
        ACTIVITY/85,,,GN2F;
        ACTIVITY/86,,;
;
;The following statements unload the first K-loader at the
aircraft.
;
        AWAIT(92),AIRC/1;
        AWAIT(93),MP70/1;
        AWAIT(94),MP50/3;
        ACTIVITY/87,RNORM(20,4,7),1;
        FREE,AIRC/1;
        FREE,KL40/1;
        FREE,MP70/1;
        FREE,MP50/1;
        TERMINATE;
;
;The following statements load the second K-loader at the
dock.
;
GN2F    AWAIT(95),DOCK/1;
        AWAIT(96),MP70/1;
        AWAIT(97),MP50/3;
        ACTIVITY/88,UNFRM(4,27,8),1;
        FREE,DOCK/1;
        FREE,MP70/1;
        FREE,MP50/3;
;
;The following statements unload the second K-loader at the
aircraft.
;
        AWAIT(98),AIRC/1;
        ACTIVITY/89,RNORM(20,4,9),1;
        FREE,AIRC/1;
        FREE,KL40/1;
        FREE,MP70/1;
        FREE,MP50/4;
        FREE,TUGS/1;
        FREE,WORK/1;
;
;The following statements prepare the aircraft for take-off
```

```
and terminate the aircraft entity.
;
        ACTIVITY/90,UNFRM(5,22,2),1;
        FREE,PARK/1;
        TERMINATE;
;
;The following statements mark the end of the network and
the end of the simulation program.
;
        ENDNETWORK;
FIN;
```

Appendix D: Model Verification

This appendix presents the results of a segment of the model verification process. Specifically, it summarizes the results of four structured interviews with supervisory personnel at WPAFB's air freight terminal. The respondents were provided with explanations of the models' assumptions, designs, and outputs. They were then asked to ordinally rate the "reasonableness" of the models' assumptions, designs, and outputs. A review of the results led to the conclusion that both models were reasonable representations of the WPAFB air freight ramp operation. Questions and responses are provided in the following list and in Table XXIV.

Questions

1. How reasonable are the models' descriptions of your air freight workload?

2. How reasonable are the models' descriptions of your facilities?

3. How reasonable are the models' descriptions of the aircraft you service?

4. How reasonable are the models' descriptions of your MHE and manpower use and availabilty during ramp operations?

5. How reasonable are the models' assumptions regarding facility use and availability during ramp operations?

6. How reasonable is the aircraft creation process in Model 1?

7. How reasonable is the aircraft creation process in Model 2?

8. How reasonable is the parking process in both models?

9. How reasonable are the aircraft queueing and selection processes in both models?

10. How reasonable is the aircraft unloading process in both models?

11. How reasonable is the aircraft loading process in both models?

12. How reasonable is the dockside K-loader unloading process in both models?

13. How reasonable is the dockside K-loader loading process in both models?

14. How reasonable is the hot spot loading process in both models?

15. How reasonable is the waiting process for terminating aircraft in both models?

16. How reasonable is the sequence of L-100 service operations as presented in both models?

17. How reasonable is the sequence of L-188 service operations as presented in both models?

18. How reasonable are the estimates of MHE, manpower, and facility use, and aircraft service times from the outputs of Model 1?

19. How reasonable are the estimates of MHE, manpower, and facility use, and aircraft service times from the outputs of Model 2?

TABLE XXIV

Question Responses

QUESTION NUMBER	REPRESENTATION OF REALITY: VERY UNREASONABLE	SLIGHTLY UNREASONABLE	SLIGHTLY REASONABLE	VERY REASONABLE
1	0	0	0	4
2	0	0	0	4
3	0	0	0	4
4	0	0	1	3
5	0	0	1	3
6	0	0	0	4
7	0	0	3	1
8	0	0	1	3
9	0	0	0	4
10	0	0	0	4
11	0	0	0	4
12	0	0	0	4
13	0	0	0	4
14	0	0	3	1
15	0	0	0	4
16	0	0	0	4
17	0	0	0	4
18	0	0	0	4
19	0	0	0	4

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This thesis identified an Air Force need for an accurate, timely means of determining an air freight terminal's material handling equipment (MHE) and manpower requirements. The need was then justified by a review of pertinent literature. To maintain a workable scope, the research addressed ramp operations only. Then, two SLAM II simulation models were developed, verified, and validated.

The models differed in the way arriving aircraft were created. Model I generated aircraft using a separate create node for each aircraft while Model 2 used a single create node for all aircraft. The air freight ramp operation at Wright-Patterson AFB, OH provided the necessary data for model development and validation. Mann-Whitney U tests and small sample tests for the difference between two means were used to test the models' ability to predict MHE and manpower requirements at the 95% confidence level. Also, Model 1, at the 95% confidence level, proved to be a better predictor than Model 2. Lastly, the models were recommended as methodological guides for the development of an air freight terminal resource requirement determination model.

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